U.S. Department of the Interior
U.S. Geological Survey

Abstracts from "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies"

Information and Technology Report
USGS/BRD/ITR–2001-0003

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Edited by
R.E. Stewart, Jr., C.E. Proffitt, and T.M. Charron

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

U.S. Geological Survey, Reston, Virginia: 2001

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Suggested citation:

Stewart, R.E., Jr., Proffitt, C.E., and Charron, T.M., eds., 2001, Abstracts from "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies," U.S. Geological Survey, Biological Resources Division, Information and Technology Report, USGS/BRD/ITR—2001-0003. 31 pp.

REPORT DOCUMENTATION PAGE			Form approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2001	Information and Technology Report

4. TITLE AND SUBTITLE
Abstracts from "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies"

5. FUNDING NUMBERS

6. AUTHOR(S)
Stewart, R.E., Jr., C.E. Proffitt, and T.M. Charron, editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES
U.S. Department of the Interior
U.S. Geological Survey
Biological Resources Division

8. PERFORMING ORGANIZATION REPORT NUMBER
USGS/BRD/ITR--2001-0003

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSES
U.S. Department of the Interior
U.S. Geological Survey

10. SPONSORING, MONITORING AGENCY REPORT NUMBER

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Copies of this publication are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (1-800-553-6847 or 703-487-4650). Copies also are available to registered users from the Defense Technical Information Center, Attn.: Help Desk, 8725 Kingman Road, Suite 0944, Fort Belvoir, Virginia 22060-6218 (1-800-225-3842 or 703-767-9050).

12b. DISTRIBUTION CODE

13. ABSTRACT(Maximum 200 words)

In the spring of 2000, scientists discovered a new and unprecedented loss of salt marsh vegetation in coastal Louisiana and other areas along the northern coast of the Gulf of Mexico. This dieback of salt marsh vegetation, sometimes called the "brown marsh phenomenon," primarily involved the rapid browning and dieback of smooth cordgrass (*Spartina alterniflora*). Coastal Louisiana has already undergone huge, historical losses of coastal marsh due to both human-induced and natural factors, and the current overall rate of wetland loss (25-35 mi^2 [65-91 km^2] each year) stands to threaten Louisiana's coastal ecosystem, infrastructure, and economy. On January 11-12, 2001, individuals from Federal and State agencies, universities, and the private sector met at the conference "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies" to discuss and share information about the marsh dieback. Presentations discussed trends in the progress of dieback during the summer of 2000 and in environmental conditions occurring at field study sites, possible causes including drought and Mississippi "low flow" conditions, changes in soil conditions (salinity, the bioavailability of metals, pathogens, etc.), the potential for wetland loss that could occur if above and below mortality occurs and is sustained over an extended period, advanced techniques for tracking the dieback via aerial photography and remote sensing, linkages of marsh hydrology to the dieback, and mechanisms of modeling dieback and recovery. In addition, presentations were made regarding development of a web site to facilitate information sharing and progress in preparation for requests for proposals based on an emergency appropriation by the U.S. Congress. All findings tended to support the idea that the dieback constituted a continuing environmental emergency and research and natural resource management efforts should be expended accordingly.

14. SUBJECT TERMS (Keywords)
brown marsh, coastal marsh dieback, dieback, land loss, marsh dieback, salt marsh, *Spartina alterniflora*

15. NUMBER OF PAGES
viii + 31

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified

Contents

Conversion Factors

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acres	0.4047	hectares
hectares (ha)	2.471	acres
square miles (mi^2)	2.590	square kilometers
square kilometers (km^2)	0.3861	square miles
feet (ft)	0.3048	meters
meters (m)	3.281	feet
square feet (ft^2)	0.0929	square meters
square meters (m^2)	10.76	square feet
inches	2.54	centimeters
centimeters (cm)	0.3937	inches
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees
Celsius degrees (°C)	1.8 (°C) + 32	Fahrenheit degrees

Agenda for "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies"

January 11-12, 2001, Radisson Hotel and Conference Center, Baton Rouge, Louisiana

Thursday, January 11

8:45	Welcome and Introductions. Len Bahr, Louisiana Governor's Office; and Bob Stewart, U.S. Geological Survey, National Wetlands Research Center
8:50	Charge for Meeting Participants. Governor of Louisiana Mike Foster (invited)

Plenary Overviews. Chairs: Len Bahr, Louisiana Governor's Office; and Bob Stewart, U.S. Geological Survey, National Wetlands Research Center

9:00	Science for Understanding Change in Coastal Ecosystems and Restoring Degraded Environments. Charles Groat, Director, U.S. Geological Survey
9:20	The Setting for the Brown Marsh Phenomenon: Physical and Biological Context for Wetland Change. Donald F. Boesch, President, University of Maryland Center for Environmental Sciences
9:40	Developing Conceptual Models of Coastal Wetland Restoration: Environmental Drivers of Ecological Succession. Robert R. Twilley, University of Louisiana at Lafayette, Director, Center for Ecology and Environmental Technology
10:00-10:20	Break
10:20-12:00	Concurrent Sessions I and II

Concurrent Session I. Aerial Photography, Satellite Imagery, and Models for Tracking and Analyzing Marsh Dieback. Chairs: Jimmy Johnston, U.S. Geological Survey, National Wetlands Research Center; and Tim Osborn, National Oceanic and Atmospheric Administration

10:20	Characterizing the Brown Marsh Spectral Response at the Plant and Canopy Level with Hyperspectral and Temporal Remote Sensing Data. Elijah Ramsey and Gene Nelson, U.S. Geological Survey, National Wetlands Research Center; Sijan Sapkota, Kristine Martella, and Amina Rangoonwala, Johnson Controls World Services Inc., National Wetlands Research Center
10:40	Remote-Sensing Methods for Marsh Dieback Identification and Delineation. Rob Cunningham, Louisiana State University, Center for Coastal, Energy, and Environmental Resources; Russell Watkins, 3001, Inc.; and DeWitt Braud, Louisiana State University, Department of Geography and Anthropology
11:00	Marsh Dieback Aerial Photography: Overview and Prospects. Lawrence R. Handley and William R. Jones, U.S. Geological Survey, National Wetlands Research Center
11:20	Aerial Mapping of Marsh Dieback in Saline Marshes in the Barataria-Terrebonne Basins. Greg Linscombe, Louisiana Department of Wildlife and Fisheries; Robert Chabreck, Retired, Louisiana State University; and Steve B. Hartley, U.S. Geological Survey, National Wetlands Research Center
11:40	Hydrologic/Spatial Model Approach to Evaluating Marsh Dieback. Joseph N. Suhayda and Vibhas Aravamuthan, Louisiana Resources Research Institute, Louisiana State University, and Paul Kemp, Louisiana State University, Center for Coastal, Energy, and Environmental Resources

Concurrent Session II. Studies of Dieback in Different Marshes and Evaluation of Causes and Effects. Chairs: C. Edward Proffitt, U.S. Geological Survey, National Wetlands Research Center; and Paul Kemp, Louisiana Governor's Office and Louisiana State University

10:20 Sudden Salt Marsh Dieback: Update from 20 Experimental Sites in Terrebonne and Barataria Basins. Karen L. McKee, U.S. Geological Survey, National Wetlands Research Center; Irving A. Mendelsshon, Louisiana State University, Wetland Biogeochemistry Institute; and Michael D. Materne, U.S. Department of Agriculture, Natural Resources Conservation Service

10:40 Statewide Distribution of Brown Marsh as Determined from Aerial Surveys. Thomas C. Michot and Christopher J. Wells, U.S. Geological Survey, National Wetlands Research Center; and Greg Linscombe, Louisiana Department of Wildlife and Fisheries

11:00 Characterization of Plants and Soils in a *Spartina alterniflora* Saltmarsh Experiencing "Brown Marsh" Dieback in Terrebonne Parish, Louisiana, USA. Thomas C. Michot, U.S. Geological Survey, National Wetlands Research Center; Mark A. Ford, Patricia S. Rafferty, Scott Kemmerer, and Troy Olney, Johnson Controls World Services Inc., National Wetlands Research Center

11:20 Marsh Surface Elevation Response to Water Level Variations in a Stressed *Spartina alterniflora* Marsh (Old Oyster Bayou). Donald R. Cahoon, U.S. Geological Survey, National Wetlands Research Center; Brian C. Perez and Bradley Segura, Johnson Controls World Services Inc., National Wetlands Research Center; and James Lynch, U.S. Geological Survey, National Wetlands Research Center

11:40 The Physical Determinants of Sediment Salinity and Their Relationship to the Brown Marsh Phenomenon in Louisiana. James T. Morris, University of South Carolina, Department of Biological Sciences

12:00-1:00 Lunch and Luncheon Speaker. Coastal Restoration—The Investment We Cannot Afford Not to Make. Mark Davis, Coalition to Restore Coastal Louisiana

1:00-1:40 Concurrent Sessions I and II continued

Concurrent Session I Continued. Aerial Photography, Satellite Imagery, and Models for Tracking and Analyzing Marsh Dieback. Chairs: Jimmy Johnston, U.S. Geological Survey, National Wetlands Research Center; and Tim Osborn, National Oceanic and Atmospheric Administration

1:00 Remote Sensing and Brown Marsh. Tim Osborn, National Oceanic and Atmospheric Administration; Shea Penland, University of New Orleans; and Craig Harvey, John C. Stennis Space Center, PixSell, Inc.

1:20 Development of a Soil Erosion Model to Predict Vulnerability of Various Marsh Ecosystems. Jerry J. Daigle, Natural Resources Conservation Service, U.S. Department of Agriculture; and Steve B. Hartley, U.S. Geological Survey, National Wetlands Research Center

1:40 Questions from the Audience and Discussion

Concurrent Session II Continued. Studies of Dieback in Different Marshes and Evaluation of Causes and Effects. Chairs: C. Edward Proffitt, U.S. Geological Survey, National Wetlands Research Center; and Paul Kemp, Louisiana Governor's Office and Louisiana State University

1:00 Dieback in *Spartina alterniflora* Marshes Along the Southwest Louisiana Coast. Keith R. Edwards, McNeese State University, Louisiana Environmental Research Center; C. Edward Proffitt and Steven Travis, U.S. Geological Survey, National Wetlands Research Center

1:20 Determining the Role of Plant Pathogens in the Coastal Marsh Dieback: Lessons from Agriculture and Forestry. Raymond W. Schneider and John P. Jones, Louisiana State University Agricultural Center, Department of Plant Pathology and Crop Physiology

1:40 Preliminary Studies of Brown Marsh in a Chenier Plain, *Spartina patens* Marsh. J.A. Nyman, Louisiana State University, Wildlife and Fisheries, School of Forestry; A.K. Burcham, University of Louisiana at Lafayette, Department of Biology; J.D. Foret, National Marine Fisheries Service, Lafayette Field Office; G. Melancon, Louisiana Department of Wildlife and Fisheries, Rockefeller Wildlife Refuge; T.C. Michot, U.S. Geological Survey, National Wetlands Research Center; and T.J. Schmidhauser, University of Louisiana at Lafayette, Department of Biology

2:00-3:00 Concurrent Sessions III and IV

Concurrent Session III. Socioeconomic Implications of Brown Marsh and Coastal Wetland Loss. Chair: Rex H. Caffey, Louisiana State University Agricultural Center/Louisiana Sea Grant, Department of Agricultural Economics and Agribusiness

2:00 Why Should You Care About Land Loss in Coastal Louisiana? Steve Mathies, Battelle Memorial Institute

2:20 Federal Emergency Management Agency's Role in Natural Hazards Such as the Recent Marsh Dieback. Rod E. Emmer, Federal Emergency Management Agency

2:40 Brown Marsh and Coastal Land Loss: The Role of Resource Economics. Rex H. Caffey and Richard F. Kazmierczak, Louisiana State University Agricultural Center/Louisiana Sea Grant, Department of Agricultural Economics and Agribusiness; and Mark Schexnayder, Louisiana State University Agricultural Center/ Louisiana Sea Grant

Concurrent Session IV. Forecasting the Big Picture: Evaluation of Climate, River Flow, and Other Factors as They Relate to Salt Marsh Dieback. Chair: Charles Demas, U.S. Geological Survey

2:00 Climate Assessment of the South Louisiana Drought. Jay Grymes, Louisiana State University, Louisiana Office of State Climatology

2:20 The Influence of River Discharge, Coastal Water Levels, and Climate on Extreme Salinity Events in the Louisiana Coastal Marshes. Erick M. Swenson, Louisiana State University, Coastal Ecology Institute

2:40 Salt Marsh Dieback and Fault-Induced Subsidence in Coastal Louisiana: An Interim Report. Sherwood M. Gagliano, Coastal Environments, Inc.

3:00 Break

Plenary Session. Natural Recovery and Restoration. Chairs: Sue Hawes, U.S. Army Corps of Engineers-New Orleans; and Greg Grandy, Louisiana Department of Natural Resources

3:20 Use of Department of Natural Resources Monitoring Data for Evaluating Marsh Dieback, Recovery, and Restoration Needs. Gregory D. Steyer and Darin M. Lee, Louisiana Department of Natural Resources

3:40 New Approaches to Revegetating Eroding Marsh. Tim Croughan, Louisiana State University Agricultural Center, Rice Research Station

4:00 Questions from the Audience and Discussion

6:00-8:30 Reception. Privately Sponsored

Friday, January 12

Plenary Session. Marsh Dieback Causes, Effects, and Data Management. Chair: C. Edward Proffitt, U.S. Geological Survey, National Wetlands Research Center

8:00	Variability of Marsh Soil Response to Drought Conditions: Water Balance and Interstitial Salinities. Christopher M. Swarzenski, U.S. Geological Survey; and Mark A. Ford and Brian C. Perez, Johnson Controls World Services Inc., National Wetlands Research Center
8:20	Recovery Potential of *Spartina alterniflora* in Dieback Areas: A Greenhouse Pilot Study. Rebecca J. Howard, Christopher J. Wells, and Karen L. McKee, U.S. Geological Survey, National Wetlands Research Center; and Thomas E. McGinnis II, Johnson Controls World Services Inc., National Wetlands Research Center
8:40	The Potential Role of Soil Metal Toxicity in Marsh Dieback. Paul L. Klerks, University of Louisiana at Lafayette, Department of Biology
9:00	Brown Marsh Effects on Habitat Functions and Fishery Species. Lawrence P. Rozas, National Marine Fisheries Service, and John W. Fleeger, Louisiana State University, Department of Biological Sciences
9:20	Coastal Wetlands Information and Data Internet Repositories that Support the Ongoing Salt Marsh Dieback Resource Management and Restoration. Scott Wilson, U.S. Geological Survey, National Wetlands Research Center
9:40	Panhandle Salt Marsh Mortality: A Prelude to Louisiana Brown Marsh? Paul R. Carlson, Jr., Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute
10:00	Break

Concurrent Session V. Panel Discussion of Science Needs. Chairs: C. Edward Proffitt, U.S. Geological Survey, National Wetlands Research Center; Kerry St. Pé, Barataria-Terrebonne National Estuary Program; and Robert R. Twilley, University of Louisiana at Lafayette, Center for Ecology and Environmental Technology

10:20	Causes of Marsh Dieback. Irving A. Mendelsshon, Louisiana State University, Wetland Biogeochemistry Institute
10:30	Status, Trends, and Modeling of Marsh Dieback. Jimmy Johnston, U.S. Geological Survey, National Wetlands Research Center
10:40	Data Management. Denise Reed, University of New Orleans
10:50	Remediation of Marsh Dieback. Greg Grandy, Louisiana Department of Natural Resources
11:00-12:00	Discussion
11:30-12:30	Lunch and Luncheon Speaker. Global Change in Coastal Systems: Patterns Possibly Affecting Frequency of Drought. Virginia Burkett, U.S. Geological Survey, National Wetlands Research Center

Plenary Session. Reducing the Risks and Effects of Marsh Dieback and Loss. Chairs: Quinn Kinler, U.S. Department of Agriculture, National Resources Conservation Service; and Bill Good, Louisiana Department of Natural Resources

12:30	Louisiana at the Crossroads. R. King Milling, President, Whitney National Bank
12:50	Old River Control Project. Charles E. Shadie, Mississippi Valley Division, U.S. Army Corps of Engineers
1:10	Options for Diverting Mississippi River Water and Sediment. Timothy Axtman, U.S. Army Corps of Engineers-New Orleans

1:30	"Brown Marsh" Demonstration Projects to Test Effectiveness of Remediation Strategies. Kenneth Bahlinger, Gregory M. Grandy, and Bill Good, Louisiana Department of Natural Resources, Coastal Restoration Division
1:50-2:10	Closing Remarks. What's Next? Kerry St. Pé, Barataria-Terrebonne National Estuary Program; Len Bahr, Louisiana Governor's Office; and Bob E. Stewart, U.S. Geological Survey, National Wetlands Research Center

Abstracts from "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies"

Edited by

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Abstract

In the spring of 2000, scientists discovered a new and unprecedented loss of salt marsh vegetation in coastal Louisiana and other areas along the northern coast of the Gulf of Mexico. This dieback of salt marsh vegetation, sometimes called the "brown marsh phenomenon," primarily involved the rapid browning and dieback of smooth cordgrass (*Spartina alterniflora*). Coastal Louisiana has already undergone huge, historical losses of coastal marsh due to both human-induced and natural factors, and the current overall rate of wetland loss (25-35 mi^2 [65-91 km^2] each year) stands to threaten Louisiana's coastal ecosystem, infrastructure, and economy. On January 11-12, 2001, individuals from Federal and State agencies, universities, and the private sector met at the conference "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies" to discuss and share information about the marsh dieback. Presentations discussed trends in the progress of dieback during the summer of 2000 and in environmental conditions occurring at field study sites, possible causes including drought and Mississippi "low flow" conditions, changes in soil conditions (salinity, the bioavailability of metals, pathogens, etc.), the potential for wetland loss that could occur if above and below mortality occurs and is sustained over an extended period, advanced techniques for tracking the dieback via aerial photography and remote sensing, linkages of marsh hydrology to the dieback, and mechanisms of modeling dieback and recovery. In addition, presentations were made regarding development of a web site to facilitate information sharing and progress in preparation for requests for proposals based on an emergency appropriation by the U.S. Congress. All findings tended to support the idea that the dieback constituted a continuing environmental emergency and research and natural resource management efforts should be expended accordingly.

Key words: brown marsh, coastal marsh dieback, dieback, land loss, marsh dieback, salt marsh, *Spartina alterniflora.*

Introduction

In the spring of 2000, scientists discovered a new and unprecedented loss of salt marsh vegetation in coastal Louisiana and other areas along the northern coast of the Gulf of Mexico. This dieback of salt marsh vegetation, sometimes called the "brown marsh phenomenon," presented a new challenge for coastal Louisiana, which has already undergone huge, historical losses of coastal marsh.

Wetlands in coastal Louisiana are currently converting to open water at a rate of 25-35 mi^2 (65-91 km^2) each year. Years of agricultural practices that involved draining wetlands and the development of networks of levees and canals have altered hydrology and caused saltwater intrusion, leading to wetland loss. Natural processes such as storms, subsidence, and sea-level rise have also contributed to wetland loss. State and Federal agencies along with private industries have joined forces in recent years to slow this change and alleviate associated problems. Coastal wetlands are important because they provide a habitat for a significant number of migratory and breeding birds and wildlife as well as a nursery area for shrimp and crawfish, a recreational area for a thriving tourist economy, and a first-line defense against tropical storms and hurricanes. Many people and industries will be displaced if the pattern of loss continues.

The rapid browning and dieback throughout coastal Louisiana of a usually tolerant intertidal plant community dominated by smooth cordgrass (*Spartina alterniflora*) sent out a resounding alarm for residents who face the significant problem of land loss. No dieback as extensive as this had been observed in Louisiana in recent history, and marsh death could very well lead to marsh loss. Although the phenomenon occurred primarily throughout coastal Louisiana, it had also been observed in parts of Texas and Florida.

Immediately after the large scale of the dieback was first documented, the U.S. Geological Survey's National Wetlands Research Center initiated field sampling on vegetation and environmental conditions at several sites and began to identify the areas affected through use of its float plane. Other agencies and university scientists also began to discuss the problem, and air and land surveillance of certain marshes was initiated. The office of the Governor took the lead in hosting meetings to document the scope, identify causes, and develop an overarching and comprehensive response to this important environmental crisis. This ultimately took the form of an Executive Order by the governor and a special emergency appropriation by the U.S. Congress to provide funding for research, tracking, and restoration.

In January 2001, the conference "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies" was held to present and discuss the findings of the studies that occurred during the dieback, to review environmental patterns of climate and Mississippi River flow, to compare the dieback with similar, smaller scale phenomena from other locations, and to further detail the scope of the biological and economic problems caused by marsh dieback.

While it is not unusual for patches of marsh vegetation to die in some years, this particular dieback occurred on a much broader scale and in areas up to 5 acres (2.0 ha). Approximately one-third of the 390,000 acres (157,833 ha) of salt marshes in the Barataria-Terrebonne basins of Louisiana was affected. Also, marshes in other locales throughout coastal Louisiana suffered marsh vegetation dieback. In these afflicted areas, most of the aboveground marsh was dead. When the dieback was first observed, the disease state was unknown and was complicated by a visible variation in the color of marsh ranging from green to brown and dead plants in various stages of degradation.

One of the factors that received prominent focus at the conference was the question of interstitial salinity. Although some studies found salinity levels well within tolerance limits for *S. alterniflora*, other studies found them to be marginally high.

The drought and unusually high summer temperatures of 2000 recorded across dieback areas was also a topic of much discussion. Several presenters pointed out the connection between reduced rainfall, lowered water levels, and increased salinity. Others noted that coastal water levels are more wind-driven than tidal, and that water drawdowns in study areas correlated with prolonged westerly and northerly winds associated with the protracted La Niña event.

Other researchers focused upon the possible role of pathogens, primarily fungi. While some found several of these agents active within the roots and crowns of *S. alterniflora* collected from test sites, further greenhouse testing will be needed to determine if they played a causative role or were merely an opportunistic phenomena associated with already dying grasses.

Several other possible contributing factors were explored as well. One was that the combined factors of drought and increased salinity might possibly have worked to increase the concentration and bioavailability to toxic metals in the soils. Another researcher felt that fault-induced subsidence along the Gulf of Mexico might have played a role.

Along with the search for causes, possible consequences and solutions to the phenomenon were examined as well. One serious concern was for the $3.8 billion market-based value of the region, especially the health of the coastal fisheries that produce much of this revenue. It was noted that shrimp and crab populations are positively correlated to the amount of marsh edge available because the juveniles of these species rely upon these liminal zones for protective cover and foraging grounds.

A highlight of the conference was an open panel discussion about short and long-term science needs for the marsh dieback. Congressional emergency appropriations through the National Oceanic Atmospheric Administration were also discussed.

Ultimately, the success of any future recovery and management solutions relies heavily upon advanced technologies and access to science information. This conference was a first attempt to open lines of communication in order to increase access to information about and understanding of the coastal dieback plaguing much of coastal Louisiana.

Robert Stewart, Jr., director of the U.S. Geological Survey's National Wetlands Research Center and Len Bahr, Louisiana Governor's Office, gave the opening address. Keynote speakers at the conference included the Director of the U.S. Geological Survey, Charles Groat; President of the University of Maryland's Center for Environmental Sciences, Donald Boesch; and Director for the Center for Ecology and Environmental Technology, University of Louisiana at Lafayette, Robert Twilley.

Governor of Louisiana Mike Foster, as well as representatives from the offices of Louisiana's U.S. Senators John Breaux and Mary Landrieu, attended part of the conference. Several government agencies and private sector entities sponsored and contributed to the conference: 3001, Inc.; Burlington Resources, Inc.; Castex LaTerre, Inc.; Entergy; Louisiana Department of Natural Resources; Louisiana Department of Wildlife and Fisheries; National Oceanic and Atmospheric Administration; Society of Wetland Scientists; U.S. Army Corps of Engineers; U.S. Department of Agriculture's Natural Resources Conservation Service; U.S.

Environmental Protection Agency; U.S. Fish and Wildlife Service; and U.S. Geological Survey.

The authors were provided the opportunity to amend these abstracts, but some declined to do so. Those unrevised abstracts were edited for USGS style only.

Plenary Overviews

January 11, 2001

Science for Understanding Change in Coastal Ecosystems and Restoring Degraded Environments

Charles G. Groat, U.S. Geological Survey

Understanding changes in ecosystems depends on knowing how these systems work and having a monitoring system capable of detecting changes in the system itself and in the conditions and processes that shape it. While understanding individual components of an ecosystem may be single-discipline based, understanding the system as a whole depends on an integrated approach to research program design and implementation, monitoring, and modeling. Restoration of ecosystems should be based on these scientific understandings, which must be communicated in an effective and timely manner to decisionmakers.

The current extent of the brown marsh problem reflects a change in the coastal wetland ecosystem, and the extent of wetland loss reflects a change in the overall coastal ecosystem complex. There is broad interest in "fixing" these problems through restoration. Sound science, effectively communicated, is an essential element in successful ecosystem restoration. Science is important both for setting the goals for restoration and for monitoring progress toward the goals.

A major challenge facing the scientific community is providing a comprehensive and connected understanding of the ecosystem as a whole, rather than individual single-discipline pieces that must be assembled like a jigsaw puzzle by the program decisionmakers. Models and decision support tools are critical to providing the integrated information that is needed for successful restoration.

The scientific community has responded quickly to the brown marsh problem. As a member of that community, the U.S. Geological Survey looks forward to continuing our efforts to ensure that what is known, and what will be learned in future, is used effectively for successful restoration of Louisiana's coastal wetlands.

The Setting for the Brown Marsh Phenomenon: Physical and Biological Context for Wetland Change

Donald F. Boesch, University of Maryland Center for Environmental Science

My vantage point on the crises that confront the coastal wetlands of the northern Gulf of Mexico is one influenced by both ancestral attachment and present detachment, by a decade of responsibility for advocacy of the generation and use of science, and by a subsequent decade as occasional advisor and critic. Based on this background I have been asked to set the stage, but, like the rest of you, I remain challenged by the bewildering complexity of the physical and biological processes that shape these ecosystems and determine their future.

The scientific and management perspectives on coastal wetland loss have tended to emphasize either long-term processes, such as delta building and destruction cycles, or recent human activities, such as canals and marsh management. Often lost among these disparate viewpoints is the substantial importance of environmental variability and episodic events. The brown marsh phenomenon commands our attention to the importance of transient events that greatly affect coastal wetlands, including biological outbreaks, hurricanes, droughts, and interannual and interdecadal variations in climate. For example, multiyear trends and cycles in tidal water levels now seem to have been an important factor in the rapid wetland losses of coastal wetlands observed in the 1970's.

The 2000 brown marsh surprise may be but a glimpse into a more uncertain future as humankind's uncontrolled experiment with the Earth's climate system plays out. Contrary to the trends observed over much of the country, precipitation in coastal Louisiana declined during the 20th century, and several climate models predict decreased precipitation together with warmer temperatures and more extended summers along the northern Gulf of Mexico Coast in the 21st century. Clearly our efforts to sustain coastal wetlands into the future must take into fuller account not only the secular trends that we will have to contend with (e.g., sea-level rise) but also the consequences of dramatic transient events (e.g., sea-level fluctuations and changes in the frequency and intensity of storms, droughts, and floods). Maybe, the year 2000 will be seen as not so strange after all.

Developing Conceptual Models of Coastal Wetland Restoration: Environmental Drivers of Ecological Succession

Robert R. Twilley, University of Louisiana at Lafayette, Center for Ecology and Environmental Technology

Restoration ecology includes the development of diagnostic capabilities for ecological systems that are based on ecological theory of succession and ecosystem development. These diagnostic capabilities are presently limited by the ability of scientists, engineers, and managers to: (1) anticipate ecological responses of ecosystems to specific manipulations or site conditions; (2) monitor responses of ecosystems at sufficient space and time scales to validate these responses; and (3) modify designs and operations of rehabilitation

projects according to the response of ecosystems to obtain specific goals. One of the most difficult tasks in restoring ecological systems is to first perform diagnostics as to what factors are responsible for deteriorating conditions (or health) of the ecosystem. Better early diagnostics would allow managers and engineers to select the proper set of conditions for site remediation techniques necessary to rehabilitate habitats toward a specifically defined goal. Thus, a fundamental need of restoration ecology is cause and effect monitoring leading to development of diagnostic tools that can be used to predict, monitor, and validate the response of ecosystems to rehabilitation criteria. Restoration ecology requires a monitoring program that will investigate the successional trajectories of ecosystems in response to a specific evaluation as to what has caused ecosystem damage. This presentation will focus on conceptual and simulation models that presently describe successional trajectories of coastal wetlands of Louisiana. The objective is to evaluate whether these models and paradigms adequately describe abnormal conditions that may have contributed to the "brown marsh" phenomenon of summer 2000. Destabilization of marsh sediments has been historically related to chronic waterlogging stress that is linked to reductions in plant growth. Yet marsh damage during the severe drought over the last 12 months suggests that water levels have been below average in the coastal zone of Louisiana. Thus, conceptual models that explain marsh dieback due to waterlogging stress may not be appropriate to explain the patterns of brown marsh observed during the summer of 2000. This presentation will focus on integrating hydrologic and biogeochemical processes that affect marsh stability and are likely to be modified by environmental drivers.

Special Plenary Presentations

January 11, 2001

Coastal Restoration—the Investment We Cannot Afford Not to Make

Mark Davis, Coalition to Restore Coastal Louisiana

Louisiana and this nation are facing a crisis. Despite the best efforts that have been marshalled to date, coastal Louisiana is still disappearing at an alarming rate of more than 25 mi^2 each year. Without bold, decisive action Louisiana as we now know it—geographically, culturally, and economically—may cease to exist in the next 50-100 years. The resulting loss would be incalculable and would be compounded by the fact that it did not have to be. If the unthinkable should occur it would not be because we were overtaken by events, but because we did not rise to the challenge when there was still time.

There is still time to act but it is running frighteningly short.

Hurricane Georges and our ongoing drought have made it ever clearer that our coastal crisis is not merely "an environmental" problem. Coastal collapse robs us of tax base, storm protection, private land rights, wildlife and fisheries habitat, dependable freshwater supplies for drinking and industrial use. Increasingly businesses and community leaders in the private sector are recognizing they are at risk. Banks, utilities, insurance companies and others are joining with the traditional coastal constituencies to say that if we do not recognize the role our coastal wetlands, waters, and barrier shorelines play in providing for and protecting our communities, culture, and economy then we cannot adequately justify the investment that will be needed to save our coast.

Indeed, the bottom line question is not whether we can afford the projected $14 billion price tag of implementing the Coast 2050 plan over the next 20 years, but whether we can afford not to make the investment. Can we afford the increased storm risks to our communities and the costs of protecting them? Can we afford higher insurance rates or the prospect that many communities and businesses will find themselves uninsurable? Can we afford to lose the billions of dollars of oil and gas and transportation infrastructure that is at risk? Can we afford to lose a multi-billion dollar a year fishery or the very natural resources that define our communities and draw billions of tourism dollars to this state each year? The answer to these questions must be of course not.

Yet without a definite decision to take the lead in implementing Coast 2050 our answer will be in effect "yes." This is the time for a new understanding of what coastal restoration is all about. This is the time for a new commitment to the stewardship of our coast. This is the time for leadership.

We believe there are three key elements of this "new understanding" and "new commitment":

1. We must understand the consequences of failing to act.
2. We must have a vision of a "restored" coast and a plan for achieving that vision. The State/Federal Coast 2050 plan is the best expression of this vision and it should be pursued and refined.
3. We must make commitments to:
    a. Sound management
    b. Public accountability
    c. Adequate funding
    d. Leadership by the State of Louisiana

Ultimately, the third element is the most crucial. In the more than 15 years that we have been working on coastal issues the most fundamental lesson we have learned is that if we—the State of Louisiana—do not take the lead, if we do not demonstrate that we take our coastal crisis seriously then no one else will do it for us. The rest of this nation will not act if we won't.

We cannot afford to wait for the rest of the nation to wake up to our problem before we stir ourselves. We can and must make our case and lead by example. That means this legislature, our Governor, and the sundry constituencies in this state need to pull together to find a way to fulfill and expand the promise of the Coast 2050 plan.

In the near term that would entail several specific steps:

1. Reform state laws and policies that impede or drive up the cost of coastal restoration projects. Presently this state does not know what lands and waters it owns and, according to recent court decision, does not even have the right to cancel or amend oyster leases in areas that will be affected by restoration projects.
2. Develop the technical support to better evaluate, design, and monitor coastal projects.
3. Require that all state programs and resources be better coordinated and prioritized to maximize efficiency and accountability and to lessen the likelihood that we are putting people and infrastructure in harms way or working at counter purposes.
4. Undertake to better ascertain the economic implications of coastal land loss. As long as coastal restoration work is viewed as an environmental program and not as à broad survival campaign, we are destined to fail.

January 12, 2001

Global Change and Coastal Systems: Patterns Possibly Affecting Frequency of Drought

Virginia Burkett, USGS National Wetlands Research Center

During the 20th century, average temperature increased by approximately 1°F, and precipitation increased by 5 to 10% across most of the United States, mostly in the form of heavy rainfall (rainfall > 2 inches/day). In the Southeast, temperature increases since 1950 have been modest compared with that of other regions, but annual rainfall trends show very strong increases of 20-30% or more over the past 100 years across Mississippi, Arkansas, South Carolina, Tennessee, Alabama, and parts of Louisiana. The timing of rainfall has also changed over the past century, and models suggest that future trends in temperature and rainfall could affect the frequency of both drought and flood events in areas such as the Mississippi River floodplain and the northern Gulf of Mexico coastal zone.

Climate simulation models (general circulation models or GCM's) used in the U.S. National Assessment suggest that average temperatures in the Southeast could rise by 2-3 °F by 2030 and by 4-10 °F by 2100. The GCM's predict more precipitation in the form of rainfall, more rainfall in the form of heavy downpours, and faster evaporation of water, leading to greater frequency of both very wet and very dry conditions. Sea surface temperature in the equatorial Pacific is predicted to resemble a more steady-state, El Niño-like condition by 2100, which suggests that fewer hurricanes will make landfall in the gulf coast, but that rainfall associated with both hurricanes and La Niña events will be more intense. In addition, sea-level rise is predicted to accelerate due to global warming 2- to 5-fold over the next century. Sea-level rise will likely continue to have serious impacts on low-lying coastal marshes, particularly in Louisiana where Holocene deltaic sediments are dewatering and compacting due to natural processes and man's development activities.

Changes in precipitation extremes (both droughts and floods) caused by increased temperature and humidity will likely have major effects on the structure and function of coastal ecosystems. Seasonal patterns indicate that projected changes will be greatest in the winter months, but large increases in summer temperature are projected by most GCM's for most of the Gulf Coastal Plain. Changes in growing season length, photosynthesis, and evapotranspiration rates will affect the potential range of many plant species, as well as competition among species. Mild southeastern winters since 1970 have already enhanced species such as the invasive, freeze-intolerant Chinese tallow tree (*Triadica sebifera*), at the expense of native hardwoods.

Although there is uncertainty inherent in any predictive modeling effort, the models and historical trends presented in the National Assessment provide a plausible set of climatic and ecological scenarios for the 21st century. The implications of the changes in climate that are simulated by most climate models present serious issues for those responsible for the conservation of coastal resources. One of five key findings of the National Assessment is that "natural ecosystems appear to be the most vulnerable to the harmful effects of climate change." The rate of ecological change that is likely to occur will not allow for the gradual migration or genetic adaptation of many species, particularly when coupled with habitat fragmentation, invasive species, and other consequences of development activities by humans. However, some practical and potentially effective strategies to minimize impacts to coastal ecosystems have emerged. Insights about climate change and its likely impacts should be core tools for coastal resource managers who are engaged in activities such as land acquisition, water resources negotiations, habitat restoration, invasive species control, fisheries and waterfowl management, and, in general, planning for the future.

Plenary Sessions

Natural Recovery and Restoration

Use of Department of Natural Resources Monitoring Data for Evaluating Marsh Dieback, Recovery, and Restoration Needs

Gregory D. Steyer, USGS National Wetlands Research Center; and Darin M. Lee, Louisiana Department of Natural Resources, Coastal Restoration Division

Large expanses of Louisiana's dominant salt marsh grass, *Spartina alterniflora*, are dying. Since the dieback's initial discovery in 2000, investigations have been conducted to document extent and degree of impact. The most noticeable observation was that there were limited amounts of data available to evaluate extent and causal factors. This is not

unusual. Rarely are large-scale natural systems sufficiently monitored to address landscape-level changes.

Salt marsh diebacks have been documented in Louisiana since the 1970's. In all cases, data were collected only after identification of the phenomenon, leading to speculation regarding causal factors. The magnitude of the current event is unprecedented, both in terms of scale and impacts over a short time period, elevating the importance of understanding how these events develop. A comprehensive baseline data set is necessary to proactively address these recurring problems.

In coastal Louisiana, monitoring emergent marsh structure and function is conducted primarily by the Louisiana Department of Natural Resources and the U.S. Geological Survey's National Wetlands Research Center under the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA). CWPPRA is monitoring 60 projects throughout the Louisiana coastal zone; however, most of these projects are spatially removed from the delineated dieback areas. An exception was the Lake Chapeau Dredge Material and Hydrologic Restoration (TE-26) project. Investigations of hourly salinity and water level data collected since 1997 indicated a three-fold increase in mean spring salinity and a single drainage event of 491 hours within the period of noticeable dieback. There was a 20% decrease in the period of marsh flooding in 2000 compared to 1997-99. Preliminary assessments of these data allowed scientists to focus research questions, define study sites and provide additional data sets to complement research initiatives.

To address the aforementioned problem of spatial and temporal data gaps, a Coast-wide Reference Monitoring System (CRMS) is being proposed for CWPPRA monitoring in Louisiana. Seven hundred reference sites will be established in the coastal zone, and many brown marsh causal factors (salinity, marsh elevation, water depth, duration and frequency of flooding, etc.) will be measured. The data will be used to establish baseline conditions across all coastal vegetation types, including those susceptible to dieback. The data set will lend itself to analyses that evaluate functional condition of dieback sites, changes in dieback sites through time compared to nondieback reference sites, and trajectories of recovery at restored and natural dieback sites.

New Approaches to Revegetating Eroding Marsh

Tim Croughan, Louisiana State University Agricultural Center, Louisiana Agricultural Experiment Station

A team of collaborating scientists from the Louisiana State University Agricultural Center and the U.S. Department of Agriculture's Natural Resources Conservation Service is working on a project to develop better methods for vegetating eroding wetlands. The team includes plant breeders, biotechnologists, disease and insect experts, soil scientists, and wetlands ecologists. Initially focusing on smooth cordgrass (*Spartina alterniflora*), the team is developing genetically improved plants for erosion control use. Concurrently, improved propagation methods are in development, with the goal of expediting the establishment of vegetation across large acreage both quickly and economically. Towards this end, a seed-based system for planting the marsh is in development. Ultimately, this approach may allow hundreds of acres a day to be planted by air at a fraction of the cost of current planting practices.

Marsh Dieback Causes, Effects, and Data Management

Variability of Marsh Soil Response to Drought Conditions: Water Balance and Interstitial Salinities

Christopher M. Swarzenski, USGS; and Mark A. Ford and Brian Perez, Johnson Controls World Services Inc., USGS National Wetlands Research Center

Salt marshes in coastal Louisiana received below-average inflows of river water and precipitation during the fall and winter of 1999 and most of 2000. Coastal water levels were lower than the long-term average during some of this time. The resulting shorter durations and fewer occurrences of tidal marsh inundation, coupled with the long-term drought, reduced the amount of water available to replenish water lost through evapotranspiration from the marsh surface and substrate. The water balance and salinity in the shallow marsh subsurface likely were affected in ways that contributed to the widely observed dieback of salt marshes in coastal Louisiana during the spring and summer of 2000. Dieback typically occurred in the marsh interior, some distance away from a canal, bayou, or other surface-water body. Marshes close to surface-waters generally survived. Another, less common, pattern was a heterogeneous mixture of dieback and surviving interior marshes. The purpose of this work was to assess whether differential soil response to the drought conditions could help explain observed patterns of salt-marsh dieback. Of particular interest was why some interior marshes survived the drought.

We measured moisture content and soil salinity of marsh soils sectioned in 3-cm or 10-cm increments up to a depth of 50 cm at sites exhibiting differing degrees of dieback and/or stress. Grain sizes of the same soil layers also were determined. Preliminary results showed soil water amounts and soil salinity levels vary considerably from site to site. Water content in the soil appeared more disjunct with depth in dieback marshes than in healthy marshes but not necessarily lower overall. In some instances, interstitial salinity was higher in healthy marshes than in adjacent dieback areas. The reverse was true for other nearby sites. The single highest interstitial salinity was 70 parts per thousand (ppt), with several values above 50 ppt. Most values were around 35-40 ppt. Grain-size distribution varied from creek edge to the marsh interior and from marsh to marsh. At one location that

was studied more intensively, marsh in sandy soils closer to areas of surface-water exchange survived, whereas marsh dieback occurred in sandy soils more distant from this exchange. Additional sites are being studied to determine general patterns of interior marsh dieback in relation to soil properties.

Recovery Potential of *Spartina alterniflora* in Dieback Areas: A Greenhouse Pilot Study

Rebecca J. Howard, Christopher J. Wells, and Karen L. McKee, USGS National Wetlands Research Center; and Thomas E. McGinnis II, Johnson Controls World Services Inc., USGS National Wetlands Research Center

Field observations in midsummer 2000 of *Spartina alterniflora* plants affected by the dieback phenomenon indicated that, in some areas, belowground tissues were affected as well as aboveground tissues. A pilot greenhouse study was conducted to ascertain if the potential ability of affected plants to resume growth (i.e., recover) under favorable environmental conditions varies with plant condition. Sections of marsh (30 cm diameter x 30 cm deep) were collected 1 August 2000 from the following five zones of qualitatively defined plant categories (types): healthy *S. alterniflora* (not affected by dieback), stressed *S. alterniflora* (browning and frayed culms), dead *S. alterniflora* (no live aboveground culms), dead *S. alterniflora* with *Batis maritima* stems, and dead *S. alterniflora* with a single *Avicennia germinans* stem. After a 2-week acclimation period the sods were placed within larger tubs. Water within the tub was maintained at the sod sediment surface, and water salinity was raised to 20 ppt. In the healthy, stressed, and dead sods, repeated measures were taken of total live and dead stem numbers and maximum live stem length. In *Avicennia* and *Batis* sods, overall plant height and number of lateral nodes were recorded over time.

During the 9-week study, dead *S. alterniflora* culms did not recover in the dead *Avicennia* or *Batis* sods. *Avicennia germinans* and *B. maritima* continued to increase in height and initiate new lateral nodes throughout the study. Comparisons between the healthy, stressed, and dead *S. alterniflora* sods indicated a significant difference between all types at all measurement times. Number of live stems and maximum stem length in healthy sods remained significantly greater than that in stressed sods throughout the study. Although new stems were produced in stressed sods, the mean number of live stems did not significantly increase over time. These results indicate that sites within dieback areas with complete *S. alterniflora* aboveground and belowground tissue death may not recover naturally unless a new source of propagules (seeds, rhizome fragments) is introduced. In such areas, any secondary species such as *A. germinans* and *B. maritima* may have an important role in helping maintain marsh integrity until *S. alterniflora* can become reestablished.

The Potential Role of Soil Metal Toxicity in Marsh Dieback

Paul L. Klerks, University of Louisiana at Lafayette

The 2000 mass marsh-vegetation die-off did not appear to have coincided with a sudden increase in levels of heavy metals or other environmental contaminants. However, metals could have been involved in marsh vegetation mortality by several other mechanisms. First, the extended drought conditions could have resulted in metals already present in the environment becoming concentrated in the remaining pore water. Second, changes in salinity, pH, and especially redox potential of marsh soil could have resulted in changes in metal speciation and metal bioavailability. An increased salinity (resulting in decreased metal uptake) could have resulted in the deficiency of an essential metal. A decrease in pH could have resulted from pyrite oxidation and caused increased uptake of toxic metals. There is some evidence for the role of pH in the current dieback (see presentations by Nyman et al. and by McKee et al.). Metal mobilization due to acidification caused by reflooding of a desiccated marsh has been reported previously. The influence of soil redox potential on metal bioavailability is rather complex, with many metals being redox sensitive, with effects of redox potential not being unidirectional over the range of redox conditions, and with effects differing among metals. Redox potential also affects the formation of deposits (plaques and concretions) on *Spartina* roots, and these deposits reduce the uptake of toxic reduced species of Fe, Mn, and S as well as nutrients. It has been reported that occurrence of deposits differs between streamside plants and inland plants, which happens to correlate with the marsh browning pattern and thus indicates that the deposits could play an indirect role. In summary, some early evidence and various hypothetical pathways support the notion that metals could have played a role in the marsh browning.

Research to address the potential role of metal toxicity in the marsh dieback should assess what changed in metal bioavailability occurred in concert with the marsh dieback. For example, greenhouse experiments could look at changes in plant tissue metal levels and plant health status under various scenarios for environmental conditions (such as changes in salinity, pH, water-level, redox) hypothesized to have been responsible for the marsh vegetation dieback.

Due to lack of funding for brown marsh research during 2000, no results are currently available on this aspect of the brown marsh issue. The aim of this presentation was to point out the potential of metal toxicity and promote future research into the evaluation of this potential.

Brown Marsh Effects on Habitat Functions and Fishery Species

Lawrence P. Rozas, NOAA, National Marine Fisheries Service; and John W. Fleeger, Louisiana State University

Coastal Louisiana supports one of the most productive fisheries in the United States, and most fishery species use estuarine nursery areas during their early lives. The young of these species, including brown shrimp, white shrimp, blue crab, spotted seatrout, southern flounder, and red drum, depend on the flooded marsh surface, and more specifically, the marsh edge for food and protection from predators. Food and refuge functions provided at the marsh edge influence population size by enhancing the growth and survival of these young animals during their estuarine-dependent stages. Population sizes of brown shrimp, white shrimp, and blue crab in a marsh are positively related to the amount of marsh edge per unit area. Thus at the landscape scale, populations of these species in a marsh system are dependent on the pattern of marsh:water interspersion (i.e., how patches of vegetation are distributed within water). The brown marsh phenomenon has the potential to affect fishery resources because it threatens not only the amount of marsh available for exploitation by fishery species but also is likely to alter spatial patterns of marsh and water in the coastal zone. We can examine the effects of this phenomenon by measuring the distribution of nekton densities in healthy and affected areas. Functional attributes of the marsh may be affected by the brown marsh phenomenon in a number of ways. Meiofauna, important prey of young fishery species (especially juvenile shrimp), are closely associated with marsh plants, and their populations may decline as emergent vegetation is lost in die-off areas. We can assess the effect of the dieback on this food resource by monitoring meiofaunal populations and examining the diets of selected fishery species in affected and healthy marshes. The refuge function also will likely diminish in dieback areas as vegetated marsh is converted to bare substrate, and this should be reflected by differences in nekton densities between healthy and affected marshes. How the brown marsh phenomenon affects fishery populations likely will depend on the size of the affected area, how long denuded areas remain unvegetated, and marsh:water interspersion patterns that develop as a result of this phenomenon.

Coastal Wetland Information and Data Internet Repositories that Support the Ongoing Salt Marsh Dieback Resource Management and Restoration

Scott Wilson, USGS National Wetlands Research Center

We have always needed information to get our jobs done; however, when we are faced with a potential crisis situation, like the dieback of thousands of acres of coastal Louisiana salt marsh in the spring of 2000, managers and scientists must rapidly assess available datasets to help determine a reasonable course of action. Additionally, when the response effort involves such a large number of diverse shareholders, rapid data collection and dissemination are essential to reduce confusion and to help establish a cooperative effort. Through a concerted and cooperative effort, environmental information and data are expeditiously being made available to management groups and the public. The data are being made available in industry standard formats that allow the user to import the data into a variety of analysis and display tools. The following web sites significantly contributed environmental datasets, historical summaries, or other products that have assisted in the ongoing brown marsh study.

The Breaux Act web site, www.LAcoast.gov, contains information that relates directly to the restoration of coastal wetlands. The site was created to link agencies together that have datasets on coastal wetlands and restoration. The site includes digitized color-infrared aerial photographs, satellite information, delineated GIS data, and many fact sheets and presentations about the brown marsh phenomenon. The site is updated daily with new data and information. The Louisiana Department of Natural Resources (LDNR) and the U.S. Geological Survey Water Resources Division have partnered in the collection of real-time hydrology data in the brown marsh area. These data can be found at www.savelawetlands.org/oldsite/spartina.htm or la.water.usgs.gov/hydrowatch.htm. Along with real-time hydrological data, the LDNR site, www.savelawetlands.org, also contains updated restoration monitoring reports in support of the Breaux Act and other coastal restoration projects. The Barataria-Terrebonne National Estuary Program site, www.BTNEP.org, contains information about ecological management and other action plans currently being implemented in the Barataria-Terrebonne Basin. The NOAA–National Marine Fisheries Service has established a site, www.coastmarshgrass.org, dedicated to satellite classification of the impacted area.

Panhandle Salt Marsh Mortality: A Prelude to Louisiana Brown Marsh?

Paul R. Carlson, Jr., Laura A. Yarbro, Frank X. Courtney, Tim Leary, Herman Arnold, Drew Leslie, John Hughes, and Nadine Craft, Florida Marine Research Institute

Several episodes of marsh mortality with symptoms similar to brown marsh occurred in the Florida Panhandle between 1990 and 1995. At sites in St. Joseph's Bay and Adams Beach, patches of smooth cordgrass (*Spartina alterniflora*) up to 1 ha in area became chlorotic, wilted, and died completely within 1 month of the onset of chlorosis. Wilting *Spartina* was rapidly consumed by salt marsh periwinkles (*Littoraria irrorata*), but herbivory impacts were clearly secondary and unrelated to the primary cause of marsh mortality. Die-off patches occurred in lower, more frequently flooded, portions of each marsh, leaving a thin strip of surviving *Spartina* along the seaward edge.

No definite cause for Florida Panhandle marsh mortality was determined. Sediment porewater sulfide concentrations (< 1 mM) and salinity (< 35 ppt) measured at die-off and surviving marsh sites were well within normal tolerance ranges for *Spartina alterniflora*. Simultaneous occurrence of die-off at two widely separated locations suggested that

anthropogenic stresses were not involved. Unlike the drought associated with Louisiana brown marsh, we found no climatic or tidal events which coincided with salt marsh mortality in the Florida Panhandle. A fungus (*Fusarium* sp.) was isolated from dying plants, but pathogenicity was not demonstrated.

Because natural recovery of die-off sites was very slow, a pilot-scale restoration project was carried out in St. Joseph's Bay in July 1994. Two-inch transplant units of four *Spartina alterniflora* accessions (Tampa Bay, St. Joseph's Bay, Mobile Bay, and Vermilion) were grown together at a nursery and planted at six die-off sites. Survival and growth were monitored quarterly for the first year and yearly thereafter. Flooding tolerance and survival varied among accessions: Vermilion and Mobile Bay accessions had the greatest survival, and St. Joseph's Bay and Tampa Bay accessions had lower survival at all sites. Accessions with higher survival (Vermilion and Mobile Bay) also had higher root alcohol dehydrogenase (ADH) activities than St. Joseph's and Tampa Bay accessions. Survival and growth for all accessions were higher in the high intertidal zone than in the low intertidal zone. However, flooding stress alone did not invoke die-off symptoms.

Our studies of Florida Panhandle marsh mortality have several implications for brown marsh research and restoration efforts. The spatial pattern and symptoms of smooth cordgrass mortality (rapid chlorosis, wilting, and consumption by snails) are similar in Florida and Louisiana, but the scale of marsh loss is much greater in Louisiana. The tidal regime and climate of the Florida Panhandle and coastal Louisiana are also similar, but there was no discernible involvement of tidal or climatic factors in Florida Panhandle marsh mortality. The variation in performance among smooth cordgrass accessions in Florida Panhandle marshes suggests that Louisiana *Spartina* accessions should be tested in pilot plantings before large-scale restoration of brown marsh areas is attempted.

Reducing the Risks and Effects of Marsh Dieback and Loss

Louisiana at the Crossroads

R. King Milling, Whitney National Bank

As a citizen of the State of Louisiana and a banker, there is concern that Louisiana is not prepared to support long-range decisions needed to methodically prioritize and implement the steps necessary to restore its coastal wetlands and barrier reefs.

The reasons why and what options are available to begin the process of changing the paradigm so as to properly present a case which will justify the expenditure of funds will be explored.

Louisiana must comprehend the financial consequences of failing to achieve the full restoration of our marshlands. By developing and documenting such consequences, the State may be able to build the necessary consensus from both a business and political point of view which will allow us to engage our national leaders as to the need for action. There are significant detrimental consequences to our nation by failing to respond to these circumstances, but they are not self-evident, and only through the development of such a coordinated consensus can anyone expect the Federal government to take notice.

How to develop such a document which will have the effect of engaging this country in the need to expend the funds required to restore the ecological system and therefore measure the degree of restoration must be appropriately vetted, answered, and adopted.

Old River Control Project

Charles E. Shadie, USACE, Mississippi Valley Division

Old River is a distinctive river with a remarkable history. Fifty miles northwest of Baton Rouge, Louisiana, it connects the Red, Atchafalaya, and Mississippi Rivers. Like all alluvial rivers, the Mississippi winds through its valleys, caving banks and topping them during floods. Occasionally, as it meanders across its floodplain it creates or obtains a steeper route to its ultimate outlet. In the late 19th and early 20th centuries, the Atchafalaya River offered the Mississippi River a shorter outlet to the Gulf of Mexico–142 miles compared to 315. By 1951, it was apparent that, unless humans intervened, the Mississippi would take the course of the Atchafalaya. If the Mississippi changed course, it would turn the present river channel into a saltwater estuary, and the effects on southern Louisiana would be catastrophic. Likewise, the Atchafalaya River could not accept the Mississippi flow without massive flooding, extensive relocations, and the upheaval of the social and economic patterns of that area. A new route would render hundreds of millions of dollars worth of flood control projects useless along the lower Mississippi, and expensive flood control projects would be required in the newly created Mississippi delta. On September 3, 1954, Congress authorized the U.S. Army Corps of Engineers (USACE) to construct the Old River Control Project as part of the Mississippi River and Tributaries Flood Control Project (MR&T). This project was designed to prevent the Mississippi River from changing its course. Congress also mandated that the flow distribution at Old River should be maintained at approximately the same proportions as occurred naturally in 1950, then determined to be approximately 30% of the total latitude flow (combined flow in the Red and Mississippi Rivers above the control structures) passing down the Atchafalaya River on an annual basis with the remaining 70% percent passing down the Mississippi River. Flows through the Old River Control Structures (which now include a private hydropower facility) are regulated to this 70/30 distribution. This discussion reviewed the history of the Old River Control Project, the flow and sediment distribution requirements, and occasions when small deviations from the mandated distribution had occurred. Deviations in the 70/30 flow split, intended to provide short term assistance to areas which have too little or too much flow,

are infrequent and limited to no more than 2% change in latitude flow. The potential to benefit the areas affected by the brown marsh phenomenon by increasing freshwater flows in the Atchafalaya Basin using Old River Control and the potential impacts to the MR&T Project was also discussed.

Options for Diverting Mississippi River Water and Sediment

Timothy Axtman, USACE, New Orleans District

Over the past 2 decades, dozens of concepts for the diversion of Mississippi River water and sediment have been built, are under construction, or have been approved.

The Mississippi River Sediment, Nutrient, and Freshwater Redistribution study investigated these concepts to produce a comprehensive guide about the potential for the diversion of Mississippi River resources. The study also assessed the potential limitation and impacts of reallocating the river's flow and sediment. From these analyses, an array of the most efficient diversions and effective diversion techniques was developed. The Coast 2050 plan, produced under the direction of the Louisiana Department of Natural Resources under the Coastal Wetlands Planning, Protection and Restoration Act, integrated many of these concepts with publicly supported basinwide restoration strategies.

Results of the analysis of river diversion have shown that there is significant available potential for diverting river flows and sediment. This potential is controlled by river location, receiving area conditions, and achieving balance between environmental, commercial, navigation, and flood protection needs throughout the coastal system. The reintroduction of river resources into Louisiana's coastal estuaries will require focused and coordinated decisionmaking from both the governmental and public arenas. Currently some highly effective and minimally complex alternatives for diversion are being actively developed.

The presentation will cover the current state of diversion, the identified potential for diversion, and the limits of the current recommendations for diversion and actions that are being taken.

Brown Marsh Demonstration Projects to Test Effectiveness of Remediation Strategies

Kenneth Bahlinger, Gregory M. Grandy, and Bill Good, Louisiana Department of Natural Resources, Coastal Restoration Division

The term "brown marsh" has been coined to describe the very severe marsh dieback that occurred during the 1999-2000 protracted drought throughout large expanses of Louisiana's coastal marshes, particularly in salt marshes comprised of *Spartina alterniflora*. Initial investigations have indicated that approximately 20,000 acres of marsh grass have converted from dense vegetation to open mud flats with little or no vegetation to hold the soil together. The erosion potential of these areas is extremely high. Further, there are approximately 260,000 acres of marsh grass that are either moderately or severely impacted.

The Louisiana Department of Natural Resources (LDNR) is the State's lead agency for the implementation of coastal restoration projects to offset Louisiana's dramatic wetland loss. Since Act 41 of the Second Extraordinary Session of the 1981 Legislature, the LDNR has gained considerable experience in planning, constructing, operating, maintaining, and monitoring a wide variety of coastal restoration projects. Therefore, in coordination with brown marsh research efforts by other agencies, LDNR is assessing costs and the biological results of trial projects as possible brown marsh remediation alternatives and is developing the project implementation portion of a remediation plan.

The LDNR will investigate three main techniques that may address sites affected by brown marsh: dedicated dredging in order to return soil elevations to levels high enough for marsh reestablishment, stabilization of critical shorelines that are at risk due to loss of marsh vegetation, and vegetation planting trials in conjunction with the U.S. Department of Agriculture's Natural Resources Conservation Service and the Louisiana Soil and Water Conservation Districts.

The LDNR is planning to quantify the aerial extent of dedicated dredging, shoreline stabilization, and plantings that would be needed to address the problem. It is envisioned that after the trials are completed, potential project areas will be ranked by their priority of need, and the site-specific potential costs of appropriate remediation project type will be assessed. In this manner, policy makers can compare costs and the effectiveness of various combinations of remediation approaches across most of the area affected by the marsh dieback.

Concurrent Sessions

Aerial Photography, Satellite Imagery, and Models for Tracking and Analyzing Marsh Dieback

Characterizing the Brown Marsh Spectral Response at the Plant and Canopy Levels with Hyperspectral and Temporal Remote Sensing Data

Elijah Ramsey III and Gene Nelson, USGS National Wetlands Research Center; Sijan Sapkota, Kristine Martella, Amina Rangoonwala, and Yaoyang Yan, Johnson Controls World Services Inc., USGS National Wetlands Research Center

Areas of marsh dieback, commonly termed brown marsh, were first observed in parts of Texas and Florida and throughout coastal Louisiana in the spring of 2000. At dieback sites,

the normally dense and healthy intertidal salt marshes (mostly composed of *Spartina alterniflora*) rapidly browned and many ultimately died. Distribution of the dieback is widespread, and in many coastal areas it has affected a majority of the salt marsh. Although some regeneration has occurred, a growing portion of the dieback sites have converted to mud flats; a much larger percentage seems to be moving towards the same fate. Researchers from many disciplines are examining the alarming dieback phenomena. While research is not complete, most believe that extreme drought, high salinities, heat, evaporation, combined with extremely low river discharges have caused a deadly blow to the shallowly rooted smooth cordgrass.

Our preliminary investigation of the dieback phenomena was directed at developing and refining remote sensing techniques to detect the occurrence of diebacks. To pursue this objective, we initiated dieback studies at three resolutions that included the plant leaf optical properties, the canopy reflectance (the signal sensed without atmospheric influences), and the satellite temporal and spatial resolutions. As part of fulfilling this objective, we needed to detect not only the dramatic change of a healthy salt marsh to a mud flat but also the more subtle onset of the dieback (e.g., green changing to more yellow then brown) before irrevocable damage had occurred. During the summer of 2000, we identified four dieback sites at different levels of severity and distances from the coastline and one nonimpacted site further inland. At each impacted site, transects were set up that extended from the heart of the dieback to the healthiest surrounding marsh. We assumed that if hydrology was the ultimate control of the dieback, then distance from the dieback center should be accompanied by a progressive change in plant stress. The plant leaf stress should then be depicted in the change in leaf optical properties. Ultimately, these changes in optical properties are what would be remotely sensed to determine onset of dieback. We also assumed that distance from the center outward would not only provide a metric to measure against, but also a simulation of time since the onset of the dieback.

Measurements of leaf optical properties associated with plants collected along each transect suggest that certain leaf optical properties did change with distance from the impact center. In other words, changes in leaf optical properties seemed related to the suggested time-line progression of dieback. These results were critical for two reasons. First, in the early stage of impact, it is likely that changes in the leaf optical properties will be the first indicators amenable to remote sensing of impact onset and progression. Second, changes in canopy structure would only be observable when the dieback progressed to a severity level where the whole plant began to die.

Canopy reflectance is a measure of the reflected sunlight from the marsh target area and includes the leaf optical properties, canopy structure, and background. Canopy reflectance spectra were obtained from a helicopter platform at (1) the dieback center, (2) an area of healthy marsh surrounding the dieback, and (3) an intermediate area. At two dieback sites, preliminary analyses revealed no pattern in canopy reflectance changes and distance along the site transect. Examined canopy reflectance spectra from nonvegetated dieback area suggested that increased water moisture content of the background from dead to healthy marsh dampened the canopy reflectance signal. This increased background, water moisture content thereby overwhelmed the changes at the plant and leaf scale and influenced the canopy signal.

We acquired five Landsat Enhanced Thematic Mapper (ETM+) satellite images on August 1999, November 1999, January 2000, April 2000, and September 2000. Models for correcting the image data for atmospheric, geometry, and irradiance variability were generated and used to normalize all image data to apparent canopy reflectance. Although validation of the corrected image data was not performed, change over time at one dieback site seemed to suggest an increase in ETM+ red reflectance and a decrease in near infrared reflectance with time. Cursory comparisons, however, did not imply this pattern necessarily was consistent at all dieback sites. If the ETM+ short time series is validated and its accuracy estimated, it will categorize the historic development of the marsh at a specific location, and within limitations of the data collected, it will also be useful to document the rate of dieback spread.

Remote-Sensing Methods for Marsh Dieback Identification and Delineation

Rob Cunningham, Louisiana State University, Center for Coastal, Energy, and Environmental Resources; Russell Watkins, 3001, Inc.; and DeWitt Braud, Louisiana State University

3001, Inc. recently teamed with Advanced Power Technologies, Inc. to conduct a Light Detection and Ranging (LIDAR) and airborne hyperspectral scanner survey of a portion of the Alaska Pipeline and surrounding environs for the Bureau of Land Management. The data collected will be used to monitor riparian environments and develop mitigation plans for drainage related environmental hazards, such as oil spills. A similar mission is planned for coastal Louisiana in late spring, 2001, using the Rockefeller State Wildlife Refuge as a test area. Landsat Thematic Mapper satellite imagery will be analyzed to provide vegetative spectral characteristics of the refuge area conditions prior to the test flight. A knowledge-based, expert system will be evaluated for detecting the spectral/elevation variability of marsh dieback and related vegetative stress using a combination of these technologies.

Marsh Dieback Classification and Mapping

Lawrence R. Handley, William R. Jones, Calvin P. O'Neil, Christopher Wells, and Stephen Creed, USGS National Wetlands Research Center; Dennis Lichtenberg, Eric Seeger,

Jason Dugas, Jesse Thibodeaux II, Rosemary Mouton, and Norma Clark, Johnson Controls World Services Inc., USGS National Wetlands Research Center

Louisiana is experiencing the most critical coastal wetland erosion and land loss problem in the United States, accounting for nearly 80% of the nation's coastal marsh loss. Shoreline erosion rates exceed 6 m/year in more than 80% of the Louisiana coastal zone and can reach up to 50 m/year in areas impacted by hurricanes. Continually impacted by a combination of natural forces and human activity, Louisiana coastal marsh loss is an estimated 34.9 mi^2/year.

Since the initial discovery in May 2000 of large dead marsh areas along the Gulf of Mexico Coast, investigations have been conducted by the Louisiana Department of Wildlife and Fisheries and the U.S. Geological Survey (USGS), National Wetlands Research Center (NWRC) to preliminarily document extent and degree of impact. The most noticeable discovery was the limited amount of spatial and temporal data available to evaluate the extent of the problem and to assess the various causal factors. Rarely are large-scale natural systems sufficiently monitored to address landscape-level changes that occur during large disturbance events. Diebacks have been documented in coastal Louisiana since the 1970's, and most recently in Texas in 1999. Previous diebacks have been small-scale and localized. The magnitude of the 2000 event in Louisiana is unprecedented, both in terms of scale and impacts over a short time period, elevating the importance of understanding how these events originate. Early survey results along with visual studies by T. Michot, USGS, and by G. Linscomb, Louisiana Department of Wildlife and Fisheries, suggested that the severity of the dead marsh had progressed extensively. In all cases, data were collected only after the event leading only to speculation regarding the possible causes. Many coastal marsh areas are left with exposed mudflats with little vegetation to hold sediment in place. With marsh degradation at these levels, environmental effects such as wind, heavy rain, tide fluctuations, and severe storms can easily accelerate sediment erosion and coastal wetland loss.

A comprehensive baseline dataset of information was necessary to proactively address this reoccurring problem. Color infrared aerial photography was collected between September 28 and November 14, 2000. The aerial photography has been scanned at 300 dots per inch and is available on the www.LAcoast.gov website. The aerial photography for 12 coastal 1:24,000 scale USGS topographic quadrangles has been rectified and mosaicked to provide digital quadrangle coverage. An aerial photointerpretation committee was convened to prioritize areas of mapping and to develop a classification system. The photointerpretation used the available 1998 color infrared aerial photography as the basis of the change analysis from marsh to brown marsh. The resulting 1:24,000 scale maps generated from the aerial photointerpretation provide the spatial data that is necessary for an assessment of the areas of potential brown marsh restoration and remediation.

Aerial Mapping of Marsh Dieback in Saline Marshes in the Barataria-Terrebonne Basins

Greg Linscombe, Louisiana Department of Wildlife and Fisheries; Robert Chabreck, Louisiana State University; and Stphen B. Hartley, USGS National Wetlands Research Center

An aerial survey of saline marshes was conducted in the Barataria-Terrebonne basins in southeast Louisiana in August 2000. The objective of the survey was to determine the location and severity of the brown marsh dieback and to map areas with the most severe vegetative damage. This survey was conducted from a 206 Bell Jet Ranger helicopter using techniques developed over the last 30 years while conducting similar vegetation surveys. Transects flown were oriented in a north-south direction and spaced 1.87 miles (3 km) apart. Sample stations were located at a spacing of 0.5 miles (.8 km) along these transects. The saline marshes surveyed were located between Four League Bay in the west and the Mississippi River in the east. The transects extended from large bays or the Gulf of Mexico on the south end, north through the saline marsh zone into the lower portion of the brackish marsh zone. Navigation along these transects and to each station was accomplished by using a Trimble Global Positioning System (GPS) receiver (Ag 122) with differential correction and ArcView/GPSView software on a ruggedized laptop computer with a daylight readable screen. At each sample station, dominant vegetation was identified and classified by using a color index, developed by Tommy Michot, U.S. Geological Survey (USGS), as an indicator of vegetation condition. The classification green indicated normal plant appearance. The classification green/brown indicated the presence of some brown (stressed plants). The classification brown/green indicated more stressed plants than normal plants. The classification brown indicated all plants appeared stressed and the classification brown lodged indicated one of several conditions: widely spaced brown plants, short brown/black plant stubble, or exposed soil. The data were entered, compiled, and analyzed at the USGS National Wetlands Research Center. Results indicated that in both basins combined, 35% of the stations were classified as normal (green), 38% were classified as moderately stressed (green/brown and brown/green), and 27% were classified as severely stressed (brown and brown lodged). The estimated area in each category was 137,655 acres with normal vegetation, 145,935 acres with moderate vegetation damage, and 105,570 acres with severe vegetation damage. The GPS logged areas (most severely damaged) were located primarily in the Terrebonne Basin. These data provided decisionmakers and researchers with quantitative and spatial information to assist in planning short and long-term data collection, monitoring, and potential remediation.

Hydrologic/Spatial Modeling Approach to Evaluating Marsh Dieback

Joseph N. Suhayda and Vibhas Aravamuthan, Louisiana State University, Louisiana Water Resources Research Institute; and Paul Kemp, Louisiana State University, Center for Coastal, Energy, and Environmental Resources

The objective of this work is to couple climate, hydrologic, and landscape models to assist researchers in evaluating the role of recent climate conditions in contributing to marsh dieback. The modeling will integrate processes occurring at basin spatial scales and decade time scales in a way that will allow dynamic feedback to occur between hydrologic and ecological processes. The individual models have been calibrated using historic atmospheric, hydrologic and landscape data, and have been used to evaluate the interaction of landscape changes and hydrology. However in the past work little attention was given to climatic processes. The models will be used to reconstruct the variations in water level and salinity that have occurred during the last 10 years throughout the coastal wetlands of Louisiana. Along with observed weather conditions, the modeling results will provide boundary conditions for advanced site-specific biological models that simulate ecological processes at higher resolutions than is possible with regional models. In a forecasting mode, the modeling could also be used as a management tool to provide early warnings of impending climate conditions that could contribute to future marsh dieback. Due to the enormous computational challenges posed by these models, modern distributed computing platforms will be utilized and the modeling will be optimized using state of the art compiler techniques so that the full potential of available hardware would be fully realized. The simulations will be performed on the 32-node Beowulf distributed computing cluster being operated at the Louisiana Water Resources Research Institute (LWRRI) at Louisiana State University (LSU).

Remote Sensing and Brown Marsh

Tim Osborn, NOAA, National Marine Fisheries Service; Shea Penland, University of New Orleans; and Craig Harvey, PixSell, Inc., Stennis Space Center, Mississippi

Use of remote sensing for locating and monitoring of brown marsh can be achieved through a number of means. Aerial surveys by Greg Linscombe and Robert Chabreck along with Tommy Michot and others have been key in locating and determining the extent of brown marsh. Aerial photography is important to provide high-resolution imagery for studying wetland areas. Satellite imagery has been used for determining the utility of this data source for wide area monitoring of large areas of wetlands across different salinity regimes.

Remote sensing is particularly good in its use and timeliness for State and Federal agencies and local parishes. However, it is not expected that remotely sensed data can, nor should replace high-resolution aerial survey efforts. Used as a monitoring tool, remotely sensed data collected and analyzed on a regular basis will serve to maximize the State's effectiveness in these efforts by utilizing the coarser scaled, more affordable remotely sensed data to identify precisely where more expensive, more labor intensive, yet much higher resolution aerial surveys should be employed. When used together in a coordinated effort both types of imagery will be used to provide the State with better data at a lower cost in a more timely fashion to track, study, and restore or remediate coastal marshes. Looking at the remote sensing in a coordinated fashion can give scientists an important tool for day to day efforts in local study areas and also can give the State the option to expand monitoring efforts to a more comprehensive state-wide coverage of the coast to monitor the brown marsh problem for all of coastal Louisiana.

For satellite imagery, LANDSAT7 and SPOT imagery has been acquired and processed and raw imagery has been shared with all those interested in receiving the data. Both data sources are easy to acquire and have been used by many agencies and groups in the State in the past. Indeed, National Oceanic and Atmospheric Administration's (NOAA) sponsorship of using satellite imagery is to test the utility of two conventional sources of imagery that could be processed with fairly standard means and be fairly consistent in matching up to the imagery acquired by aerial surveys and also ground truthed locally working with groups in the field such as the Louisiana Department of Natural Resources (LDNR), USGS National Wetlands Research Center (NWRC) and others. Overall the following is found:

- -LANDSAT7 and SPOT can identify, locate, and monitor existing brown marsh areas on a large area basis and can track changes in areas of sizes in the 30 m diameter and larger category.
- -Both image sources can be acquired on a monthly basis and used locally for monitoring changes in brown marsh areas across both the salt and brackish marshes and for the eastern and western side of the State.
- -Processing of imagery can be done locally with a collaboration of university and contractor support working with State and Federal agencies and can serve as a means for using raw imagery for special work and also processing all the imagery using conventional techniques and providing it to users via the Internet.
- -Keeping local interaction and processing of imagery in working with State and Federal agencies can provide some important information for monitoring and remediation and restoration planning and implementation. Tracking of brown marsh areas for recovery, conversion to open water or some interim transition can also be readily in a format that can be imported and used on any geographic information system (GIS) that the State or Federal agencies or local parishes are using today.

Monitoring brown marsh areas for the next 2-3 years on a frequent basis and for the coast starting in the east but hopefully expanding it to the full state coastline should provide a good means, working with field and aerial surveys, to provide the best set of data sources for the State to assess and respond to brown marsh in the near term for the next few years.

Overall, NOAA proposes working with LDNR, Louisiana Department of Wildlife and Fisheries, the Governor's Office, NWRC, Barataria-Terrebonne National Estuary Program (BTNEP), other State and Federal agencies and local parishes, and a number of universities to help acquire, process, and distribute raw and processed imagery in formats and of areas of concern for work in the monitoring of brown marsh. The goal of providing imagery that is very current and can be processed in a few days and made available for local use is very workable. Using an interagency group of State and Federal and university representatives to provide the coordination on the frequency of obtaining imagery and the processing and distribution is the key to making this useful as possible.

Development of a Soil Erosion Model to Predict Vulnerability of Various Marsh Ecosystems

Jerry J. Daigle, USDA, Natural Resources Conservation Service; and Stephen B. Hartley, USGS National Wetlands Research Center

The Federal government recognizes soil as a strategic natural resource that must be understood, managed, and conserved for the health of the nation. The National Cooperative Soil Survey (NCSS) Program is a partnership, led by the Natural Resources Conservation Service (NRCS), of Federal land management agencies, State agricultural experiment stations, and State and local units of government that provide soil survey information necessary for understanding, managing, conserving, and sustaining the nation's limited soil resources. Soil scientists, working under the auspices of the NCSS, have completed the process of mapping the soils of the State of Louisiana.

In the coastal zone, soil characteristics such as thickness of layers, mineral soil texture, organic fiber type, firmness, potential decomposition when disturbed, water layers, salinity, and vegetation are recorded at each site observed. From the information gathered, calculations can be made related to average decomposition rates for specific layers, for combinations of layers, or for all layers. Subsidence potential can be estimated as well as depth or thickness of material loss to specific causative agents. Causative agents can be such things as increase or decrease in salinity; changes in soil reaction or pH; reduction in the amount of fresh water recharge through the system; additions of silt or sediment; changes in chemical ratios within the soil; increase in elements, compounds, or substances known to be toxic or detrimental to plant growth; or changes in chemical composition creating toxic compounds. Many of these potential causative agents are the same as those being cited as possible sources of the brown marsh dieback phenomenon.

Using calculations of predicted soil loss or predicted soil damage based on the introduction of specific causative agents, a soil loss prediction model can be developed using geographic information systems (GIS) technology. As an example, calculations were made of the predicted loss of organic soil layers resulting from increase in salinity. These calculations were made for typical soils of the Louisiana coastal zone. By predicting the soils that are most likely to be affected, the geographic areas most prone to land loss were identified. Using this technique, a land loss prediction model was demonstrated for Lafourche Parish. If soil samples were to be extracted from the brown marsh dieback areas, and if a causative agent or agents were identified, similar predictive models could be developed that would identify areas prone to similar future phenomenon.

Studies of Dieback in Different Marshes and Evaluation of Causes and Effects

Sudden Salt Marsh Dieback: Update from 20 Experimental Sites in Terrebonne and Barataria Basins

Karen L. McKee, USGS National Wetlands Research Center; Irving A. Mendelssohn, Louisiana State University, Wetland Biogeochemistry Institute; and Michael D. Materne, Louisiana State University, Natural Resources Conservation Service

Our approach to the dieback phenomenon in coastal Louisiana, 2000, has been to establish multiple sites throughout the most affected region (Terrebonne and Barataria Basins) to: (1) document the degree and pattern of damage and current status of affected areas, (2) assess potential for natural recovery, (3) identify causal mechanisms, and (4) establish reference points and baseline data against which future changes may be accurately assessed. Aerial and ground surveys were conducted in August and October 2000 from Point Au Fer to the Mississippi River, and permanent stations were established in 18 dieback and 2 control sites. At each dieback site, permanent markers were placed in three zones: a healthy zone with less than 10% mortality, a transition zone with approximately 50% mortality, and a die-off zone with greater than 90% mortality. Within each zone, three plots were randomly located where the following variables were measured: aboveground vegetative condition (species composition; percent live/dead by cover; stage of decomposition of standing dead plants); rooting depth; rhizome viability; pathogens (shoot and rhizome/root); leaf tissue elemental composition; and soil physicochemical conditions (bulk density, percent organic matter, salinity, redox potential, pH, sulfide, and extractable cation and trace metal concentrations). The die-off zone consisted primarily of stubble or leafless

stems (16 of 18 sites), indicating an advanced state of shoot decomposition and no regeneration (during this growing season) for most of the affected areas. In contrast, healthy and transition zones had live shoots and some evidence of resprouting. Examination of rhizome viability revealed that less than 5% of perennating organs in the die-off zone were alive, compared to greater than 70% in adjacent transition and healthy zones. Thus, dieback areas may be slow to recover naturally, but the healthy and transition zones will be important in stabilizing marsh edges in the short-term. Two fungal species were isolated, but pathogenicity has not been established; in any case, these organisms typically infect previously stressed plants and at most played a secondary role in the dieback. Examination of soil physicochemical conditions in the dieback areas revealed nonlethal levels of salinity, sulfide, and pH, but these values may not reflect conditions that prevailed earlier in the growing season. Further experimental work will be required to establish the precise causative mechanism.

Statewide Distribution of Brown Marsh as Determined from Aerial Surveys

Thomas C. Michot and Christopher Wells, USGS National Wetlands Research Center; and Greg Linscombe, Louisiana Department of Wildlife and Fisheries

Widespread vegetation dieback in the salt marshes of Louisiana was first observed in the spring of 2000. Monthly aerial surveys have tracked the extent of the dieback in Louisiana and Texas. Bimonthly ground surveys have begun to investigate the effects of the phenomenon. Aerial surveys were conducted in southeast Louisiana in June, August, September, October, and November, and in southwest Louisiana/southeast Texas in August and October. Results from the U.S. Geological Survey's (USGS) National Wetlands Research Center fix-winged aerial surveys in August over coastal Louisiana (2,995 sample points), combined with results from Louisiana Department of Wildlife and Fisheries helicopter surveys in southeast Louisiana (557 sample points), indicate that the greatest effect (severe and moderate browning) on saline marsh was in Terrebonne Parish (73,840 acres) followed by Lafourche Parish (55,704 acres). All parishes surveyed (Cameron, Iberia, Jefferson, Lafourche, Plaquemines, St. Bernard, St. Mary, Terrebonne, and Vermilion) showed some impacted marsh acreage in at least one of the four marsh types (fresh, intermediate, brackish, saline). Observations from aerial surveys indicate that as of the first of December 2000 most of the severely impacted sites had failed to recover. Areas characterized in June by standing dead vegetation had become mud flats completely devoid of any living or dead plant material by late November. Preliminary indications are that these severely impacted areas will remain mudflats with little chance of recovery in the short term. Additionly, since these severely impacted areas are unvegetated mudflats, they are extremely vulnerable to soil erosion and loss of soil elevation, resulting in increased potential for conversion from marsh to open water habitat. Moderately impacted areas are showing signs of becoming greener and may recover if environmental conditions improve. However, if conditions do not improve they could continue to degrade and become severely impacted sites. The conversion of emergent marsh to open water in coastal Louisiana could increase by 100,000 acres or more in the next year if current trends continue.

Characterization of Plants and Soils in a *Spartina alterniflora* Salt Marsh Experiencing "Brown Marsh" Dieback in Terrebonne Parish, Louisiana, USA

Thomas C. Michot, USGS National Wetlands Research Center; Mark A. Ford, Patricia S. Rafferty, Scott Kemmerer, and Troy Olney, Johnson Controls World Services Inc., USGS National Wetlands Research Center

Widespread vegetation dieback in Louisiana salt marshes was first observed in spring 2000. The primary species affected by this phenomenon was *Spartina alterniflora* Loisel. We established two study sites: one in a stressed salt marsh at the south end of Bay Junop in Terrebonne Parish, Louisiana, and a second nearby in a healthy reference site along Bayou du Large. At the Bay Junop site we identified five distinct zones based on color and physical appearance of the plants, ranging from green patches of living plants to brown and black patches of dead plants in various stages of degradation. Interstitial water chemistry data were collected at the Bay Junop (stressed) site in early June. We initiated detailed measurements of the plant community structure and soil physicochemical characteristics in August at the stressed site and in September at the reference site. We collected data biweekly through October, then monthly from November on. For both live and dead *S. alterniflora* stems we recorded counts and heights; for the live plants we also recorded the number of live and dead leaves and stress categories. We measured salinity, sulfides, pH, NH_4, N+N, PO_4 and Eh in interstitial waters at 15 cm (root zone) and 30 cm (below the root zone) soil depths, in the surface waters for each plot, and in the bayou adjacent to each site.

Live plant heights at the end of the growing season differed significantly ($P = 0.002$) between the stressed (mean $= 28 \pm 2.42$ cm) and reference (mean $= 42 \pm 2.92$ cm) sites. At the stressed site the mean number of stems and height of dead stems in early August were 28.25 ($\pm$3.16) /m^2 and 21.00 ($\pm$1.44) cm, respectively. Those values decreased over time largely because of weathering, snail herbivory, and decomposition so that by mid-November, the dead zones had become unvegetated mudflats (mean dead stem counts = 8.5 ($\pm$ 1.93) / m^2; mean dead stem height = 5.28 ($\pm$ 1.41) cm). Interstitial sulfides, salinity, pH, and soil Eh were not significantly different by depth between sites. Salinity and sulfide levels were significantly different ($P = 0.001$) among sampling dates at both 15 and 30 cm for both sites. Interstitial sulfides were generally less than 2 mM within the root zone and tended to

be higher in the Bay Junop live zone and in the reference site than in the Bay Junop dead zones. Salinity ranged from approximately 18 to 30 g/L^{-1} at all depths, well within tolerance limits for *S. alterniflora*, and pH was slightly basic. Soils were oxidized within the root zone of the reference site (mean Eh = 48 mV) but were reduced at the stressed site where mean redox was approximately -45mV in the root zone and as low as -100 mV below the root zone. We have seen no sign of recovery in the dead zones at Bay Junop. Sampling at both sites will continue through the winter and into the growing season of 2001 to document whether the affected site continues to degrade, becomes stable, or recovers.

Marsh Surface Elevation Response to Water Level Variations in a Stressed *Spartina alterniflora* Marsh (Old Oyster Bayou)

Donald R. Cahoon, USGS National Wetlands Research Center; Brian C. Perez, Bradley Segura, Johnson Controls World Services Inc., USGS National Wetlands Research Center; and James Lynch, USGS National Wetlands Research Center

Surface Elevation Table (SET) measurements were first taken in 1992 at Old Oyster Bayou (OOB), which is historically a very healthy *Spartina alterniflora* marsh due to its proximity to the Atchafalaya River mouth. Prior to the full-scale awareness of the marsh dieback in coastal Louisiana, 2000, three new instruments were deployed at OOB to gain a better understanding of marsh surface elevation processes. Two instruments were new versions of the original SET, one driven to a depth of 18 m (Rod SET) and the other anchored in the top 0.35 m designed to isolate the active root zone (Shallow SET). In addition, an ultrasonic sensor was included to record measurements of surface elevation every 15 min in conjunction with marsh porewater levels. Old Oyster Bayou vegetation showed significant signs of stress throughout the summer of 2000 although mortality did not occur.

Coastal Louisiana water levels are essentially wind-driven with tidal signatures often overridden due to the small tidal range in the northern gulf coast. The data collected at OOB reflected this, showing prolonged drawdowns in regional water levels in response to westerly and northerly winds. A concomitant lowering of marsh water levels occurred via evapotranspiration. Interestingly, marsh surface elevation data were highly correlated with marsh water level perturbations. As water levels rose in the marsh following a drawdown, surface elevation rebounded rapidly to approximately its previous level. During the most extreme water level drawdown measured (-18 cm), however, marsh surface elevation showed a much more delayed response following water level increases and did not show a 100% recovery until after 5 weeks. This result suggested that a large drawdown event for several weeks may add additional stress to the marsh vegetation due to lack of easily extractable water. Data from the three versions of SET's revealed that as marsh water level dropped, the marsh surface elevation decreased because of dewatering and compaction of the substrate below the root zone. The root matrix remained intact and moved vertically with changes in water status below the root zone. Together, these data suggested that sediment composition may play an important role in water retention and availability and may have been a factor in the spatial distribution of the brown marsh phenomenon.

The Physical Determinants of Sediment Salinity and their Relationship to the Brown Marsh Phenomenon in Louisiana

James T. Morris, University of South Carolina

Sediment salinity in intertidal marshes is determined by a number of interactive physical variables. These include the physical properties of sediment such as permeability and field capacity, evapotranspiration rate, the elevation of the site relative to mean sea level, and the salinity of the flood water. Intertidal marshes occupy a position that is high within the intertidal zone, near the mean high tide. At this position the marsh may not flood on a regular basis. This can happen during neap tides or at times when mean sea level is unusually low as was the case in the Mississippi River Delta region during the summer of 2000. Mean monthly sea level varies seasonally due to thermal expansion and contraction, and the amplitude of this seasonal cycle was reduced during 2000. This reduced the frequency of flooding and would have also reduced losses of solutes by drainage and diffusion while increasing the evaporation of water from the sediment. This will increase the magnitude and variability of porewater salinity. By this mechanism, changes in mean sea level are great enough to have a significant impact on sediment salinity and, consequently, plant growth. Sediment salinity can also rise due to increases in evapotranspiration and flood water salinity caused by drought or reduced freshwater discharge. In the region of the Mississippi River Delta, there is a normal seasonal pattern of surface water salinity with lows during the summer, but surface salinity during 2000 was high throughout the year due to a low Mississippi River discharge. The situation was worsened by record low rainfall in the region, which increased the sediment water deficit and salinity. In summary, a record local drought, lower than normal mean water level, and low Mississippi River discharge combined to raise the salinity of the sediment. A salt balance model of the sediments, coupled with a sedimentation model that allows the marsh surface to equilibrate with local mean water level, predicted that this combination of events could have raised the sediment salinity to lethal levels.

Dieback in *Spartina alterniflora* Marshes Along the Southwest Louisiana Coast

Keith R. Edwards, Louisiana Environmental Research Center, McNeese State University; and C. Edward Proffitt and Steven Travis, USGS National Wetlands Research Center

The marsh dieback of 2000 is perceived to be a threat to coastal Louisiana. While the factors producing the dieback are still mostly unknown, such a phenomenon is expected to lead to a greater loss of important salt marsh habitat, as well as subsidence and loss of land in the coastal zone. Most of the focus has been on the dieback events in the Barataria and Terrebonne basins, due to the large extent of this phenomenon in these areas. However, dieback events have occurred also along the Gulf of Mexico Coast in southwest Louisiana, in the Chenier Plain. Dieback areas have been found in the Sabine National Wildlife Refuge (NWR). In these areas, *Spartina alterniflora* plants (and sometimes *S. patens*) browned quickly over the summer. The plants in the affected areas appeared green and healthy in mid to late May 2000, but they were dead or dying by late July 2000.

We have measured live stem density in a 19-year-old restored salt marsh in Sabine NWR since mid-August 2000. Density measurements were taken in five zones within the marsh: (1) the low edge of the marsh adjacent to Long Point Bayou; (2) 1 m inland from the marsh edge; (3) 6 m inland from the marsh edge; (4) 60 m inland from the marsh edge; and (5) a green, unaffected area, roughly 120 m inland from the marsh edge. Five replicate quadrats (0.04 m^2) were surveyed in each zone during each sampling period. Stem densities were also measured in a nearby natural, unaffected marsh. Live stem densities remained constant in the green and low edge zones, ranging from 150 to 350 stems/m^2, from August 2000 to July 2001. However, live stem densities decreased in the other three zones from August to December 2000, to as low as 10 stems/m^2 in the 60 m zone. There has been natural regrowth since December 2000 in the 1 m and 6 m zones (to 75 and 20 stems/m^2, respectively), while densities remain very low in the 60 m zone.

There were no significant differences in live stem densities among the natural, unaffected marsh and those found in the low edge and green zones of the dieback marsh ($F_{1,8}$= 4.13; p = 0.077). However, there were significant differences between the affected zones in the dieback marsh and the unaffected, natural marsh ($F_{1,16}$= 34.03; p = 0.0005). Also, live stem densities were significantly greater in the low edge and green zones compared to the three affected zones ($F_{4,20}$= 38.89; p = 0.0005). These data show that the interior zones of this marsh suffered from a dieback event, and that those affects are still apparent almost 1 year after the initial event occurred.

We established a small restoration experiment in the dieback marsh in September 2000 to determine whether the conditions that produced the initial dieback were still operating and whether restorative plantings might be a viable management technique to reduce the loss of marsh habitat. Plugs from a known genotype of *S. alterniflora* were transplanted into the green, 60 m, and 1 m zones of the dieback marsh. Ten replicate plugs (20 x 20 x 20 cm soil and root mass with numerous emerging healthy stems) were transplanted into each zone. Another 10 plugs were dug from the donor clone and then immediately replanted back into the donor clone; these acted as controls. This particular donor clone was chosen based on its morphological and growth characteristics, as compared to other typed-clones. The chosen clone had high survivor and growth rates along elevation and moisture gradients normally found in these salt marshes. Also, it has a much less dense growth pattern, with taller stems, which gives it more of a distinctive appearance than the other clones it was tested against.

The stems of the transplant plugs had turned brown by November 2000 due to transplant shock, but new shoots began emerging in December 2000. By May 2001, survivorship of the transplant plugs ranged from 70-91%, approaching that of the controls (100% survival). Mean stem density and stem height (13.0 stems/plug and 86.25 cm, respectively) were greatest in the 60 m zone, while much reduced in the green and 1 m zones (green zone: 5.3 stems/plug and 53.0 cm; 1 m zone: 4.7 stems/plug and 57.1 cm). This may be due to a lack of intraspecific competition in the 60 m zone, a result of the lower degree of natural re-growth in that zone, and to drier conditions in the 1 m zone. Mean stem density and stem height of the control plugs were 3.9 stems/plug and 92.3 cm, respectively.

The factor(s) that caused the initial dieback during summer 2000 no longer seem to be operating, based on the results of the transplant experiment. The success-to-date of this experiment shows that this may be a useful restoration method in dieback marshes that have little natural regrowth or colonization. Such transplants would help to prevent or minimize sediment loss due to erosion.

Determining the Role of Plant Pathogens in the Coastal Marsh Dieback: Lessons from Agriculture and Forestry

Raymond W. Schneider and John P. Jones, Louisiana State University Agricultural Center

We began isolating possible pathogens from *Spartina alterniflora* collected from sites adjacent to dieback-affected areas in coastal Louisiana during the fall of 2000. Several fungi were recovered from roots and crowns of plants that showed early dieback symptoms but that had not succumbed. Included were species of *Fusarium*, common decay organisms, pythiaceous fungi, and unidentified isolates. These fungi will be evaluated in extensive pathogenicity tests to determine if they cause symptoms similar to those associated with dieback. However, it must be emphasized that results from these tests will be preliminary, and that attributing a syndrome (numerous symptoms) to a particular pathogen requires

extensive experiments under environmental conditions that simulate the natural state. In this case, the natural state includes both increasing and fluctuating levels of salinity as well as soil water deficits. Furthermore, it is very likely that a combination of pathogens may be required to reproduce the entire syndrome, not all of which may be operative at the same time or in the same place. Thus, each isolate or combination of isolates will be used to infest soil that will be potted, planted with *S. alterniflora*, and exposed to each of the following environmental regimes: constant salinity of 20 ppt, gradual increase of salinity to about 50 ppt, and water deficits imposed by allowing flooded pots to dry via evapotranspiration.

Determining the etiological agent(s), both biotic and abiotic, for these types of diseases (catastrophic diebacks and declines) have been the stock and trade of plant pathologists since the founding of the science during the Irish potato famine of the 19th century. There are numerous instances in which decades were required for causal agents to be identified, and there are examples of missteps that led to wrong conclusions and, in some cases, inappropriate government policies that compounded the problem. A case in point is the jarrah forest decline in Australia in which large tracts of eucalyptus continue to die. The exact cause of the decline eluded investigators for many years because the pathogen (*Phytophthora cinnamomi*) is difficult to culture, and specific environmental conditions are required for infection. During the time that the forests were declining and before the causal agent had been identified, gravel from dying forests was transported long distances for road construction in unaffected areas, thus unknowingly spreading the pathogen. Another example concerns a disease of wheat known as "take-all" caused by *Gaeumannomyces graminis*. The pathogen causes lesions on roots, but the fungus is difficult to isolate because the secondary saprophytic organisms invade the lesions soon after the initial infection. These diseases and others that could be cited illustrate certain principles of plant pathology that are germane to the marsh dieback syndrome. Specifically, before pathogens can be implicated as a causal factor, the syndrome must be experimentally reproduced under environmental conditions that exist in brown marsh-affected areas.

Preliminary Studies of Brown Marsh in a Chenier Plain, *Spartina patens* Marsh

J.A. Nyman, Louisiana State University; A.K. Burcham, University of Louisiana at Lafayette; J.D. Foret, NOAA, National Marine Fisheries Service; G. Melancon, Louisiana Department of Wildlife and Fisheries, Rockefeller Wildlife Refuge; T.C. Michot, USGS National Wetlands Research Center; and T.J. Schmidhauser, University of Louisiana at Lafayette

Rapid dieback of *Spartina alterniflora* Loisel in the rapidly subsiding Mississippi River Deltaic Plain in southeastern Louisiana garnered much attention, but our study sites are dominated by *Spartina patens* (Aiton.) Muhl in the more stable Chenier Plain, which lies on the coast from central Louisiana to Galveston, Texas. Between March and May 1999, Foret, National Oceanic and Atmospheric Administration (NOAA), noted total dieback at 3 of 6 sites at Rockefeller Wildlife Refuge. Michot estimated via aerial survey that ~30% of unmanaged marsh at the refuge was brown in August 2000. In October 2000, Melancon and Nyman visited Foret's sites and observed lower salinity (28 ppt versus 31 ppt) and higher pH (6.0 versus 5.2) associated with healthy sites. Melancon and Nyman found that 22% of a 6-km transect was dead *S. patens*; all *S. alterniflora* observed was healthy. Some seed-borne species were invading the dead *S. patens* patch, but invasion appeared limited by seed availability. Burcham and Schmidhauser, University of Louisiana at Lafayette, isolated more fungal types from brown *S. alterniflora* plants than from green *S. alterniflora* plants and observed more rapid fungal growth from brown spots than from green portions of browning leaves. Our data show that dieback can be as severe in *S. patens* marsh, which is twice as common as *S. alterniflora* in coastal Louisiana. We plan to test if soil conditions likely to have occurred during the recent drought (high salinity, sulfides, and acidity) increased plant susceptibility to fungal infection.

Socioeconomic Implications of Brown Marsh and Coastal Wetland Loss

Why Should You Care About Land Loss in Coastal Louisiana?

Steve Mathies, Battelle Memorial Institute

Coastal Louisiana is a unique area of enormously valuable natural resources, all of which are dependent, in one sense or another, on the future existence of Louisiana's coastal landscape. This dependence precisely leads to the challenge that we face—preserving, protecting, and restoring our land, our homes, and our heritage in coastal Louisiana. Louisiana's coastal wetlands are important not only because of the multibillion-dollar seafood industry they support or because of their importance to waterfowl; they are also nationally significant because of the physical protection from storms and hurricanes that these wetlands provide to oil and gas production and service facilities that support nearly 27% of our nation's domestic oil and gas production and nearly 15% of all foreign oil entering the United States. Louisiana coastal wetlands provide this same type of protection for over a million people who live in these coastal areas and the levee systems that surround their communities. Louisiana's coastal landscape also helps protect the multibillion-dollar navigation industry that depends on adequate water depths and/or protected inland shipping channels for safe passage. These are but a few of the many economic activities that coexist with the

natural attributes and environmental values most often thought of when one considers the value of wetlands to our nation.

Because of a number of natural and artificial causes, Louisiana's coastal wetlands are being lost at a rate of 25-35 mi^2 each and every year. That equates to about 50 acres of Louisiana's coastal landscape being converted to open water each day. Over the next 50 years it is anticipated that about 500,000 more acres of Louisiana's coastal landscape will be converted to open water. Most people would agree that the root cause of the land loss problem is the fact that, through a federal program aimed at flood protection, levees were constructed to confine flows and to direct floodwaters conveyed by the Mississippi River to the Gulf of Mexico. Unfortunately, directing these sediment-laden floodwaters to the gulf prevents them from flowing into and nourishing the coastal landscape. These flood-protection features were implemented by the U.S. Army Corps of Engineers to protect Louisiana from flooding resulting from drainage of 41% of the continental United States, not from rainfall in the State of Louisiana.

Unfortunately, the deteriorating coastal landscape of Louisiana is also threatened by previously unknown or documented phenomenon like "brown marsh." The long-term, cumulative effect of large-scale vegetation die-off, coupled with the ongoing processes of subsidence and erosion, will likely exacerbate the already devastating land loss rate. To begin the process of formally documenting the relationship between Louisiana's coastal landscape loss problem and nationally recognized economic activities like navigation and oil and gas exploration and production, and other issues such as agriculture and fish and wildlife, the Coast 2050 feasibility study team is working directly with representatives of those affected economic activity categories. Estimates cited in the Coast 2050 Reconnaissance Report indicate that the cost of maintaining today's coastal landscape is about $14 billion over the next 20 years. Project construction is projected to begin now and to extend over the next 20 years.

Federal Emergency Management Agency's Role in Natural Hazards Such as the Recent Marsh Dieback

Rod E. Emmer, Federal Emergency Management Agency

The Federal Emergency Management Agency (FEMA) works to reduce the loss of life and property and to protect critical infrastructure from all types of hazards. FEMA accomplishes its mission through an established comprehensive management program that includes mitigation, preparedness, response, and recovery. At this time, however, natural disasters as exemplified by marsh dieback do not exist as an authority for the agency. FEMA Washington continues to assess its options on this matter and the long-term implications of its actions. In the meantime, because wetlands dampen storm surge and protect infrastructure, FEMA will join in partnership with resource agencies such as the Environmental Protection Agency, the Natural Resources Conservation Service, and the Louisiana Department of Natural Resources in addressing the brown marsh problem. FEMA believes that we can accomplish more if we cooperate together as a team, rather than as individual agencies. To this end, FEMA will share the information it possesses on coastal systems. Second, FEMA will help educate the public and decisionmakers about the problem and the value and functions of wetlands. FEMA remains focused on eliminating repetitive losses. In the future, the agency may choose to support a more resource-oriented project when the response makes a direct contribution to reducing the loss of life and property and protects infrastructure.

Brown Marsh and Coastal Land Loss: The Role of Resource Economics

Rex H. Caffey, Louisiana State University Agricultural Center/ Louisiana Sea Grant; Richard F. Kazmierczak, Louisiana State University Agricultural Center; and Mark Schexnayder, Louisiana State University Agricultural Center/Louisiana Sea Grant

Coastal erosion processes are widely documented in Louisiana, where an estimated 25-35 mi^2 of marsh are lost annually due primarily to hydrologic modification, nutrient/ sediment starvation, and subsidence. The magnitude of this problem is manifest by an increasing body of scientific literature centered on causal agents, extent of loss, and remediation techniques. To date, the vast majority of this research has been derived from the biophysical sciences, namely geology, ecology, and engineering. Though most of these studies are predicated on economic justifications, socioeconomic research is by comparison nonexistent. This disparity became more evident during the brown marsh phenomenon, in which vast expanses of the state's coastal salt marsh began to exhibit dramatically higher rates of stress and mortality. The economic implications of brown marsh are potentially severe in the Barataria-Terrebonne Estuary, where as much as 65% of the commercially vital salt marsh has been either moderately or severely impacted. Yet, scientific response to the crisis has been almost purely biophysical, with less than 2% of the emergency research funding slated for socioeconomic assessment. The lack of economic linkages to biophysical processes hinders the assessment of direct risks to the region's $3.8 billion in market-based values and thus limits the attention the issue receives in State and Federal policy. In addition, consideration of the indirect or "nonmarket" value of ecological services could significantly increase the estimated magnitude of economic risk, but contingent valuation studies of coastal Louisiana wetlands are scarce. This presentation provided tenets of market and nonmarket valuation within the context of Louisiana's brown marsh and coastal erosion crisis. Short-term priorities recommended for economic research included a current inventory of Louisiana's market-based wetland values and a meta-analysis of relevant economic research. For the long term, interdisciplinary collaboration

was promoted for developing a coast-wide assessment of nonmarket wetland values by location, attribute, and loss rate. Specific research examples were provided to illustrate the future role of resource/environmental economics in attracting, allocating, and assessing our investments in coastal restoration.

Forecasting the Big Picture: Evaluation of Climate, River Flow, and Other Factors as They Relate to Salt Marsh Dieback

Climatic Assessment of the Recent South Louisiana Drought

John M. (Jay) Grymes III, Louisiana Office of State Climatology, Louisiana State University

The onset of La Niña (El-Niño Southern Oscillation [ENSO] "cold phase") in mid 1998 set the stage for a shift to a "drier" weather pattern for Louisiana. Historical review of past "moderate to strong" La Niñas—like the recent event—indicates that a highly significant relationship exists between southern Louisiana precipitation and the establishment of La Niñas. Winter-spring rainfall has been below-normal for roughly 80% of past "mature" La Niñas—clearly a strong signal and a useful long-range forecasting tool. Unfortunately, the magnitude of these La Niña-driven rainfall deficits—the degree of "dryness"—remains difficult to predict, as does the duration of the La Niña events themselves.

Various measures of the 1998-2000 La Niña suggest that this event was likely the most significant "cold phase" event—in terms of duration—since the mid 1970's. Its impact on south Louisiana rainfall is obvious, with the past 24-month period ranking among the driest observed within the past century for many parishes. The expected winter-spring rainfall departures were compounded by summer "dryness" resulting from the unusually persistent development of an upper-level ridge over the U.S. Southern Plains, which frequently inhibited typical summer convective activity over the Louisiana coast. The result: regional monthly rainfall was below-normal for upwards of 75% or more of all months during this time frame. At the same time, temperatures tended to run above-normal, with the 1998-99 and 1999-2000 winters proving to be unusually mild. From a water-balance perspective, the combination of below-normal precipitation and elevated temperatures led to enhanced environmental moisture demand and evapotranspiration rates.

Current oceanic and atmospheric indicators suggest that the ENSO "cold phase" is reaching an end, with ENSO "neutral" conditions anticipated for the upcoming several months. Although this suggests that the probability for continuation of the recent "dry weather" trend is reduced, confidence and skill in climate forecasting for coastal Louisiana is generally weakest during ENSO "neutral" periods.

The Influence of River Discharge, Coastal Water Levels, and Climate on Extreme Salinity Events in the Louisiana Coastal Marshes

Erick M. Swenson, Louisiana State University, Coastal Ecology Institute

Water levels and salinity in Louisiana estuaries are controlled by a balance between the freshwater input from runoff and precipitation, and the salt water mixing into the estuaries at the coast through the coastal boundary layer. The coastal boundary is in turn influenced by exchange with the deeper Continental Shelf and Gulf of Mexico waters, as well as with the freshwater plume from the Mississippi River. This present study is concerned with the recently observed extremes in coastal salinities and how they relate to these forcing functions.

Data from various State and Federal sources were used to compute the deviations from the long-term (1960-2000) monthly mean for each of the forcing functions (Mississippi River Discharge, Coastal Water Levels, Precipitation, Palmer Drought Severity Index) and for the coastal salinities. Analysis of the deviations indicates that 1999-2000 has been the lowest estuarine freshwater input year in the last 40 years, and that the duration of high salinity levels has been about four times longer than what would normally be expected. The coastal water levels have been lower than normal since late 1999, the Mississippi River discharge has been extremely low, and the Palmer Drought Severity Index (PDSI) has indicated extreme to severe drought conditions in the northern Gulf of Mexico estuarine areas for about the past 18 months. The combination of this extensive drought condition and low coastal water levels may have limited local groundwater recharge. The decreased groundwater recharge, coupled with the high open water salinities, could have resulted in soil salinities high enough to adversely impact the *Spartina alterniflora* marshes. The deviation data are also being used to develop a spatial-temporal classification matrix. This matrix is being used to look at the coherence among the salinity deviations and the forcing functions in the northern gulf as well as to identify time periods during which similar conditions may have occurred. Linear Models (ANOVA, stepwise regression) were used to relate the forcing variables (monthly Mississippi River flow, monthly PSDI, monthly precipitation, and mean monthly coastal water levels) to the monthly salinity deviations for several stations. Preliminary results indicate that monthly Mississippi River flow explains about 40% of the monthly salinity deviation, the monthly precipitation explains about 10% of the monthly salinity deviation, and the coastal water levels explain less than 5% of the monthly salinity deviation. Similar results were obtained for seasonally averaged data. The model also shows that the effect of the Mississippi River discharge decreases, and the effect of precipitation increases from the coast inland. The model is being refined to look at the effect of lags of the forcing functions on the salinity.

Salt Marsh Dieback and Fault Induced Subsidence in Coastal Louisiana: An Interim Report

Sherwood M. Gagliano, Coastal Environments, Inc.

The reported extent of the brown marsh dieback phenomena, which occurred in the deltaic plain of coastal Louisiana during the drought of 2000, corresponds to a vast area of fault induced subsidence and submergence. The relationships between marsh dieback and subsidence will be discussed on a regional and site-specific basis. The implications to coastal restoration will also be discussed.

Appendix 1. State of Louisiana Proclamation

State of Louisiana
Executive Department
Baton Rouge
Proclamation No. 55 MJF 2000
Declaration of State Emergency Loss of Saltwater Marshes

WHEREAS, forty percent (40%) of the saltwater marshes in the contiguous United States are found in the state of Louisiana; nonetheless, Louisiana has lost more than fifteen hundred (1,500) square miles of marsh since 1930, which is the highest rate of land loss in the nation, and Louisiana is continuing to lose marsh at a rate of twenty-five (25) to thirty-five (35) square miles a year;

WHEREAS, saltwater marshes are vital to the state of Louisiana as both a critical component of the state's coastal wetland ecosystem and a first line of defense in the state's coordinated system to protect coastal communities against harm from storm surges and hurricanes;

WHEREAS, during the spring of 2000, state and federal officials made the alarming discovery of the "brown marsh phenomenon," an unusually extensive and rapidly spreading browning of the normally lush green saltwater marsh grass *Spartina alterniflora*, known more commonly as oyster grass or smooth cordgrass (hereafter "marsh grass");

WHEREAS, a collaborative team of state and federal officials and university scientists, coordinated by the governor's executive assistant for coastal activities, promptly mobilized to determine a) the extent of the affected marsh area, b) whether the phenomenon is spreading, c) the causes of the phenomenon, d) the possible short-term protective measures and long-term remediation and/or recovery strategies, and e) the possible funding sources for research and remediation to prevent the reoccurrence of the phenomenon;

WHEREAS, the collaborative team determined that the saltwater marsh area in the state of Louisiana primarily affected is located between the deltas of the Atchafalaya River and the Mississippi River in the parishes of Lafourche, Terrebonne, Jefferson, and Plaquemines, centering in the Barataria-Terrebonne National Estuary (hereafter "Estuary"), a fragile wetland area containing approximately 390,000 acres of saltwater marsh, of which about 110,000 acres is severely impacted and about 150,000 acres is moderately impacted;

WHEREAS, of the severely impacted saltwater marsh acreage in the Estuary, at least 17,000 acres of marsh grasses has already converted from dense vegetation to open mud flats with little or no vegetation and without roots to hold the land together and prevent erosion; consequently, it is likely that Louisiana's already staggering rate of annual land loss will be greatly exacerbated;

WHEREAS, although the investigations of the collaborative team are still on-going, preliminary findings indicate the likely cause of the phenomenon is a lack of fresh water flow resulting from record drought, record high temperatures, abnormally low water levels in the Mississippi River during the spring, and unusually low summer tides, the combination of which severely compounded the long-term effects of the nation's extensive levee system, which alters the natural fresh water flow, on Louisiana's saltwater marshes;

WHEREAS, the combination of recent events and the nation's levee system has caused a lack of fresh water and/or periodic flooding essential to saltwater marshes for replenishing the water table and maintaining the normal salinity levels of the marshes; and

WHEREAS, the brown marsh phenomenon constitutes a natural disaster, with potentially catastrophic results, and it has created an immediate threat to public health and safety, the environment, and public and private property;

NOW THEREFORE, I, M.J. "MIKE" FOSTER, JR., Governor of the state of Louisiana, by virtue of the authority vested by the Constitution and the laws of the state of Louisiana, do hereby order and direct as follows:

SECTION 1: A state of emergency is declared to exist in the parishes of Lafourche, Terrebonne, Jefferson, and Plaquemines (hereafter "parishes"), as a result of the "brown marsh phenomenon," an unusually and rapidly spreading browning of the normally lush green saltwater marsh grass *Spartina alterniflora*, which has caused an immediate threat to public health and safety, the environment, and public and private property.

SECTION 2: The state of emergency declared in Section 1 shall continue in effect until November 1, 2001, unless the state of emergency is terminated or rescinded prior to that date.

IN WITNESS WHEREOF, I have set my hand officially and caused to be affixed the Great Seal of Louisiana, at the Capitol, in the city of Baton Rouge, on this 23rd day of October, 2000.

GOVERNOR OF LOUISIANA

Appendix 2. State of Louisiana Executive Order

State of Louisiana
Executive Department
Baton Rouge
Executive Order No. MJF 2000-41
Saltwater Marsh Die-Off Action Plan

WHEREAS, forty percent (40%) of the saltwater marshes in the contiguous United States are found in the state of Louisiana; nonetheless, Louisiana has lost more than fifteen hundred (1,500) square miles of marsh since 1930, which is the highest rate of land loss in the nation, and Louisiana is continuing to lose marsh land at a rate of twenty-five (25) to thirty-five (35) square miles a year;

WHEREAS, saltwater marshes are vital to the state of Louisiana as both a critical component of the state's coastal wetland ecosystem and a first line of defense in the state's coordinated system to protect coastal communities against harm from storm surges and hurricanes;

WHEREAS, during the spring of 2000, state and federal officials made the alarming discovery of the "brown marsh phenomenon," also referred to as "saltwater marsh die-off," an unusually extensive browning and/or die-off of the normally lush green saltwater marsh grass *Spartina alterniflora*, known more commonly as oyster grass or smooth cordgrass (hereafter "marsh grass");

WHEREAS, a collaborative team of state and federal officials and university scientists, coordinated by the governor's executive assistant for coastal activities, promptly mobilized to determine a) the extent of the affected saltwater marsh area, b) whether the browning and/or die-off is spreading, c) the causes of the browning and/or die-off, d) the possible short-term protective measures and long-term remediation and/or recovery strategies, and e) the possible funding sources for research and remediation to prevent the reoccurrence of the browning and/or die-off;

WHEREAS, the collaborative team determined that the saltwater marsh area in the state of Louisiana primarily affected is located between the deltas of the Atchafalaya River and the Mississippi River in the parishes of Lafourche, Terrebonne, Jefferson, and Plaquemines, centering in the Barataria-Terrebonne National Estuary (hereafter "Estuary"), a fragile wetland area containing approximately three hundred ninety thousand (390,000) acres of saltwater marsh, of which about one hundred ten thousand (110,000) acres is severely impacted and about one hundred fifty thousand (150,000) acres is moderately impacted;

WHEREAS, of the severely impacted saltwater marsh acreage in the Estuary, at least seventeen thousand (17,000) acres of marsh grasses have already converted from dense vegetation to open mud flats with little or no vegetation and without roots to hold the land together and prevent erosion; consequently, it is likely that Louisiana's already staggering rate of annual land loss will be greatly exacerbated;

WHEREAS, although the investigations of the collaborative team are still on-going, preliminary findings indicate the likely cause of the browning and/or die-off is a lack of fresh water flow resulting from record drought, record high temperatures, abnormally low water levels in the Mississippi River during the spring, and unusually low summer tides, the combination of which severely compounded the long-term effects of the nation's extensive levee system which limits natural fresh water flow to Louisiana's saltwater marshes;

WHEREAS, the combination of recent events and the nation's levee system has caused a lack of fresh water and/or periodic flooding essential to saltwater marshes for replenishing the water table and maintaining the normal salinity levels of the marshes;

WHEREAS, because the browning and/or die-off of the saltwater marshes constitutes a natural disaster that has created an immediate threat to public health and safety, the environment, and public and private property, on October 23, 2000, the governor issued Proclamation No. 55 MJF 2000, which declares a state of emergency to exist in the parishes of Lafourche, Terrebonne, Jefferson and Plaquemines; and

WHEREAS, the Wetlands Conservation and Restoration Authority (hereafter "Authority") is the entity legislatively mandated to provide aggressive state leadership and direction in the development and implementation of the state of Louisiana's Wetlands Conservation and Restoration Plan and its wetlands related policies, the best interests of the citizens of the state of Louisiana shall be served by the Authority and the governor's executive assistant for coastal activities immediately performing duties specifically related to saltwater marsh browning and/or die-off;

NOW THEREFORE, I, M.J. "MIKE" FOSTER, JR., Governor of the state of Louisiana, by virtue of the authority vested by the Constitution and the laws of the state of Louisiana, do hereby order and direct as follows:

SECTION 1: In conjunction with its statutory duties set forth in R.S. 9:213.1, et seq., the Wetlands Conservation and Restoration Authority (hereafter "Authority"), under the direction of the governor's executive assistant for coastal activities (hereafter "executive assistant"), shall immediately take all feasible and necessary action to respond to and/or remediate the unusual saltwater marsh browning and/or die-off of the normally lush green saltwater marsh grass Spartina alterniflora, in the parishes of Lafourche, Terrebonne, Jefferson, and Plaquemines. This remedial and/or responsive action shall include, but is not limited to, completing the following actions by January 31, 2001:

A. Developing a prioritization plan for stabilizing the saltwater marsh areas in the parishes of Lafourche, Terrebonne, Jefferson, and Plaquemines (hereafter "affected parishes"), which are most severely affected by browning and/or die-off and giving priority ranking to the marsh areas considered severely or moderately impacted that are located in the vicinity of coastal communities, fresh water drinking sources, emergency evacuation routes, and/or flood protection systems;

Developing an emergency contingency plan for reintroducing a sufficient amount of freshwater to the saltwater marshes in the affected parishes to achieve normal water salinity levels, and identifying factors and/or events that would occur prior to the institution of such an emergency contingency plan;

C. Evaluating the feasibility of expediting the construction and early operation of the Davis Pond Diversion Project;

D. Evaluating the feasibility of expanding the operational functions of existing structures, such as the Old River Control Structure, pump stations, and/or navigational locks, to include non-traditional wetland restoration uses;

E. Evaluating the feasibility of expediting proposed projects to divert additional fresh water from the Mississippi and Atchafalaya Rivers; and

F. Evaluating the potential for utilizing satellite remote sensing and computer modeling technology to monitor wetland conditions and optimize management of available fresh water.

SECTION 2: As far as practicable, the executive assistant and the Authority shall collaborate and work in conjunction with the executive director of the Barataria-Terrebonne National Estuary Program to fulfill the duties set forth in Section 1 of this Order.

SECTION 3: On or before January 31, 2001, the Authority and the executive assistant shall jointly submit to the governor, through the governor's special assistant for environmental affairs, a comprehensive report which addresses the issues set forth in Section 1 of this Order.

SECTION 4: All departments, commissions, boards, agencies, and offices of the state, or any political subdivision thereof, are authorized and directed to cooperate in the implementation of the provisions of this Order.

SECTION 5: This Order is effective upon signature and shall continue in effect until January 31, 2001, unless amended, modified, terminated, or rescinded by the governor, or terminated by operation of law prior to that date.

IN WITNESS WHEREOF, I have set my hand officially and caused to be affixed the Great Seal of Louisiana, at the Capitol, in the city of Baton Rouge, on this 27th day of October, 2000.

GOVERNOR OF LOUISIANA

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Acronyms

BTNEP	Barataria-Terrebonne National Estuary Program
CRMS	Coast-wide Reference Monitoring System
CWPPRA	Coastal Wetlands Planning, Protection and Restoration Act
ENSO	El-Niño Southern Oscillation
ETM	Enhanced Thematic Mapper
FEMA	Federal Emergency Management Agency
GIS	Geographic information system
GPS	Global Positioning System
LDNR	Louisiana Department of Natural Resources
LIDAR	Light detection and ranging
LSU	Louisiana State University
LWRRI	Louisiana Water Resources Research Institute
MR&T	Mississippi River and Tributaries Flood Control Project
NCSS	National Cooperative Soil Survey
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWR	National Wildlife Refuge
NWRC	National Wetlands Research Center
OOB	Old Oyster Bayou
PDSI	Palmer Drought Severity Index
SET	Surface Elevation Table
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

REPORT DOCUMENTATION PAGE	Form approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2001	Information and Technology Report

4. TITLE AND SUBTITLE
Abstracts from "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies"

5. FUNDING NUMBERS

6. AUTHOR(S)
Stewart, R.E., Jr., C.E. Proffitt, and T.M. Charron, editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES
U.S. Department of the Interior
U.S. Geological Survey
Biological Resources Division

8. PERFORMING ORGANIZATION REPORT NUMBER
USGS/BRD/ITR--2001-0003

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSES
U.S. Department of the Interior
U.S. Geological Survey

10. SPONSORING, MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Copies of this publication are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (1-800-553-6847 or 703-487-4650). Copies also are available to registered users from the Defense Technical Information Center, Attn.: Help Desk, 8725 Kingman Road, Suite 0944, Fort Belvoir, Virginia 22060-6218 (1-800-225-3842 or 703-767-9050).

12b. DISTRIBUTION CODE

13. ABSTRACT(Maximum 200 words)

In the spring of 2000, scientists discovered a new and unprecedented loss of salt marsh vegetation in coastal Louisiana and other areas along the northern coast of the Gulf of Mexico. This dieback of salt marsh vegetation, sometimes called the "brown marsh phenomenon," primarily involved the rapid browning and dieback of smooth cordgrass (*Spartina alterniflora*). Coastal Louisiana has already undergone huge, historical losses of coastal marsh due to both human-induced and natural factors, and the current overall rate of wetland loss (25-35 mi^2 [65-91 km^2] each year) stands to threaten Louisiana's coastal ecosystem, infrastructure, and economy. On January 11-12, 2001, individuals from Federal and State agencies, universities, and the private sector met at the conference "Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences, and Remedies" to discuss and share information about the marsh dieback. Presentations discussed trends in the progress of dieback during the summer of 2000 and in environmental conditions occurring at field study sites, possible causes including drought and Mississippi "low flow" conditions, changes in soil conditions (salinity, the bioavailability of metals, pathogens, etc.), the potential for wetland loss that could occur if above and below mortality occurs and is sustained over an extended period, advanced techniques for tracking the dieback via aerial photography and remote sensing, linkages of marsh hydrology to the dieback, and mechanisms of modeling dieback and recovery. In addition, presentations were made regarding development of a web site to facilitate information sharing and progress in preparation for requests for proposals based on an emergency appropriation by the U.S. Congress. All findings tended to support the idea that the dieback constituted a continuing environmental emergency and research and natural resource management efforts should be expended accordingly.

14. SUBJECT TERMS (Keywords)
brown marsh, coastal marsh dieback, dieback, land loss, marsh dieback, salt marsh, *Spartina alterniflora*

15. NUMBER OF PAGES
viii + 31

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified

Technical Report Series

U.S. Geological Survey

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